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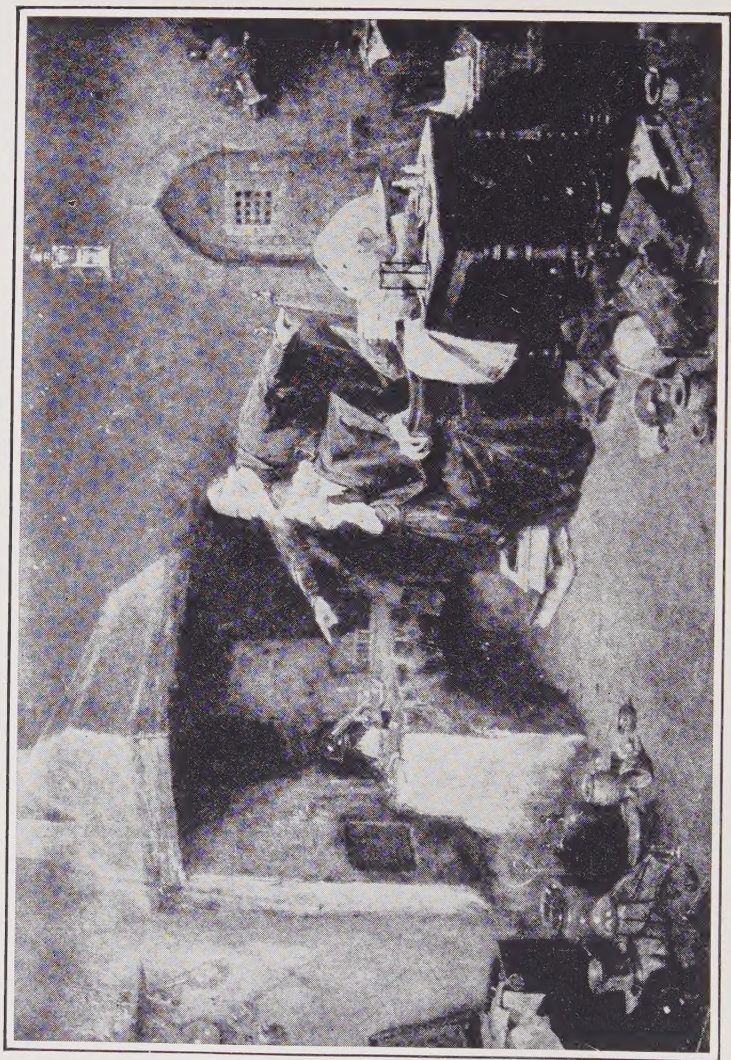


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THE ELIXIR OF LIFE
by John A. Lomax
(in the Royal Academy of England)

BERNARD JAFFE

CRUCIBLES

THE LIVES AND
ACHIEVEMENTS
OF THE GREAT
CHEMISTS



1930

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TO
THE MEMORY
OF
MY PARENTS

58/59-6

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"THERE IS FIRST THE CROPPING AFTER CAUSES, AND THEN THE STRUGGLE TO FRAME LAWS. THERE ARE INTELLECTUAL REVOLUTIONS, BITTER CONTROVERSIAL CONFLICTS, AND THE CRASH AND WRECK OF FALLEN PHILOSOPHIES." *Francis P. Venable.*

I

TREVISAN

HE LOOKS FOR GOLD IN A DUNGHILL

IN THE dark interior of an old laboratory cluttered with furnaces, crucibles, alembics, stills and bellows, bends an old man in the act of hardening two thousand hens' eggs in huge pots of boiling water. Carefully he removes the shells and gathers them into a great heap. These he heats in a gentle flame until they are white as snow, while his co-laborer separates the whites from the yolks and putrifies them all in the manure of white horses. For eight long years the strange products are distilled and redistilled for the extraction of a mysterious white liquid and a red oil.

With these potent universal solvents the two alchemists hope to fashion the "philosopher's stone." At last the day of final testing comes. Again the breath-taking suspense, again—Failure!—their stone will not turn a single one of the base metals into the elusive gold.

Secretly had the old man worked at first, for had not the Arabian master of alchemy, Geber himself, admonished his disciples: "For heaven's sake do not let the facility of making gold lead you to divulge this proceeding or to show it to any of those around you, to your wife, or your cherished child, and still less to any other person. If you do not heed this advice you will repent when repentance is too late. If you divulge this work, the world will be corrupted, for gold would then be made as easily as glass is made for the bazaars."

The quest of the Golden Grail obsessed him. As far back as

he could remember, Bernard Trevisan had thought and dreamed of nothing else. Born in 1406 of a distinguished family of Padua, oldest of the northern Italian cities, he had been reared on his grandfather's stories of the great search of the alchemists. Stories of failures, all, but he would succeed where others had failed. Encouraged by his parents, Bernard began his great adventure at the age of fourteen. His family approved, for they hoped to multiply the young heir's patrimony a thousandfold. But as the years of failure passed and his fortune slowly dwindled they lost faith as others had done. They pitied him and attributed his pursuit of alchemy to nothing short of madness.

But no failures or discouragement could dampen the hopes of the alchemist. Undeterred by the fiasco of the eggshell experiment, carried on with the aid of Gotfridus Leurier, a monk of Citeaux, he continued his labors with superhuman patience. "I shall find the seed," he whispered to himself, "which will grow into great harvests of gold. For does not a metal grow like a plant?"¹ "Lead and other metals would be gold if they had time. For 'twere absurd to think that nature in the earth bred gold perfect in the instant; something went before. There must be remoter matter. Nature doth first beget the imperfect, then proceeds she to the perfect. Besides, who doth not see in daily practice art can beget bees, hornets, beetles, wasps out of the carcasses and dung of creatures? And these are living creatures, far more perfect and excellent than metals."

For ten more long years, Bernard Trevisan followed the will-o'-the-wisp teachings of Rhazes and Geber. He dissolved and crystallized all kinds of minerals and natural salts. Once, twice, a dozen times, even hundreds of times, he dissolved, coagulated and calcined alum, copperas, and every conceivable animal and vegetable matter. Herbs, flowers, dung, flesh, excrement—all were treated with the same painstaking care. In alembics and

pelicans, by decoction, reverberation, ascension, descension, fusion, ignition, elementation, rectification, evaporation, conjunction, elevation, sublimation, and endless other strange operations, he tried everything his tireless ingenuity could conjure.

"Gold is the most perfect of all metals," he murmured. "In gold God has completed His work with the stones and rocks of the earth. And since man is nature's noblest creature, out of man must come the secret of gold." Therefore he worked with the blood and the urine of man. These operations consumed twelve years and six thousand crowns. He was surrounded by a motley group of pretended seekers after the stone—by men who, knowing the Italian rich, offered him secrets which they neither understood nor possessed. His wealth dwindled slowly as he supported all manner of adepts, for he had not yet learned that where one honest adept of alchemy is found, ten thousand cheats abound.

Finally he became tired of the knaves who had reduced him almost to penury. He rid himself of these impostors and turned his attention to the obscure and mystic works of two other masters of alchemy, Johannes de Rupecissa and Sacrobosco. His faith in the philosopher's stone revived, this time he allied himself with a monk of the Order of St. Francis. This friar had told him how Pope John XXII, during the "Babylonian Captivity," maintained a famous laboratory at Avignon where he himself labored to make gold, and as he piled up a fortune of eighteen million florins, issued bulls against the competition of other alchemists.

Thrice ten times Bernard Trevisan rectified spirits of wine "till," as he said, "I could not find glasses strong enough to hold it." This liquor would not fail him, he thought. Again the test was made—the "stone" proved as unfruitful as ever. But

the fire still burned hot within him. He buried himself in his dark dungeon of a laboratory, sweating and starving for fifteen more years in the search for the unattainable.

By now he had spent ten thousand crowns, and his health was very poor. But the fervor of the aging man was unabated. Almost maddened by failure, he betook himself to prayer, hoping that God in His goodness would select him as the deliverer of man from poverty. But the favor of the Lord was not visited upon him, and his friend, the Franciscan, died in the quest. Bernard Trevisan was alone once more.

He transported his laboratory to the shores of the Baltic Sea where he joined forces with a magistrate of the city of Trèves, who also belonged to that band of erring men impelled by an almost insane force to the strange search. "I am convinced," said this magistrate, "that the secret of the philosopher's stone lies in the salt of the sea. Let us rectify it day and night until it is as clear as crystal. This is the dark secret of the stone." So for more than a year they labored, but the *opus majus* still remained concealed.

Now Bernard, still fumbling in the dark, came upon another clew. Turning to silver and mercury he dissolved them in *aqua fortis*, a very strong acid. By concentrating the solutions over hot ashes obtained from foreign coals, he reduced their volumes to half. Then carefully he combined the two liquids, making sure not to lose a single drop, and poured the mixture into a clay crucible, which he placed in the open, exposed to the action of the sun's rays. "For does not the sun acting upon and within the earth form the metals?" he argued. "Is not gold merely its beams condensed to a yellow solid? Do not metals grow like vegetables? Have not diamonds been known to grow again in the same place where years before they had been mined?" He, too, had heard of mines being closed to give the metals an op-

portunity to grow larger. For another five years he worked with this sun-exposed mixture, filling phial after phial and waiting for the great change which never came.

Bernard Trevisan was now close to fifty years old, but the fire still burned within him with a full flame. Gathering his meager possessions, he set out in search of the true alchemists. His wanderings carried him to Germany, Spain, and France, where he sought out the famous gold searchers and conferred with them in the hope of finding the key that would put an end to his all-consuming desire.

He finally settled down in France, still working in his laboratory, when word reached him that Master Henry, Confessor to the Holy Roman Emperor, Frederick II, had discovered the secret formula of the stone. He started off to Vienna at once—and found a man after his own heart. Master Henry had been working all his life to solve the supreme riddle of transmutation. He was no deceiver, but a man of God, sincerely searching for the germ of gold. The two dreamers vowed eternal friendship, and that night Bernard, “the good,” gave a banquet in honor of his new partner, to which he invited all the alchemists of the vicinity. At the banquet-table it was agreed that forty-two gold marks should be collected from the guests. Master Henry, contributing five marks, promised to multiply the coins fivefold in the crucible. Bernard added twenty marks, while his five last surviving comrades, who had kept him company on his travels, added their little share, borrowed from their patron.

In a glass vial of strange design Henry mixed yellow sulphur with a few drops of mercury. Holding the vial high over a fire, slowly he added a few grains of silver and some pure oil of olives. Before finally sealing the glass container with hot ashes and clay, he placed in it the forty-two gold marks and a minute quantity of molten lead. This strange mixture was placed

in a crucible and buried in a red-hot fire. And while the alchemists ate and drank heartily, and chattered volubly of the great search of the centuries, the concoction in the vial boiled and bubbled unguarded in the kitchen furnace.

Patiently they waited until the vial was broken. The "experiment" was a failure. Master Henry could not understand. "Perhaps," he ventured, "some ingredient had been wanting." Others suggested that the phase of the moon and the position of the planets and stars were not propitious for such a momentous experiment. Yet was it not strange that when the crucible was emptied in the presence of the queer company that surrounded Bernard, only sixteen of the forty-two gold marks were salvaged? The other twenty-six had disappeared, perhaps to appease Hermes Trismegistus, the father of alchemy. This farce infuriated Trevisan, and he vowed to abandon the quest of the philosopher's stone.

For two weary months which seemed to go on and on forever, Bernard kept his pledge, but again that burning in his heart overcame cold reason, and his mind was set once more on retrieving his vanishing fortune through the stone. And now his thoughts turned to the cradle of alchemy—to Egypt, Palestine, Persia, Greece, Turkey, the Isle of Cyprus. For was not the father of alchemy identified with the grandson of Noah, who was intimately familiar with the philosopher's stone? Had not Sarah, the wife of Abraham, hidden an emerald tablet engraved with the cryptic directions for making gold? Had not Alexander the Great discovered it in a cave near Hebron? "Whatever is below is like that which is above, and that which is above is like that which is below, to accomplish the miracle of one thing." This he had read, and stranger things, too. "The father thereof is the sun, and the mother thereof is the moon, the wind carries it in its belly, and the nurse thereof is the earth. This thing has



FROM A GERMAN TRANSLATION OF THE CHEMICAL WRITINGS OF
 BERNARD TREVISAN
 (published in Nurnberg by Johann Krauss, 1747)

more fortitude than fortitude itself, because it will overcome every subtle thing and penetrate every solid thing. By it this world was formed." Here was the meaningful secret of the universal solvent which Hermes, the son of Osiris, King of Egypt, had discovered. Had not Jason and the Argonauts gone in search of the Golden Fleece, which was nothing else than a book of alchemy made of sheep-skin? And had not Gaius Diocletian, Roman Emperor in 290 A.D., ordered all books which treated of the admirable art of making gold committed to the flames, "apprehensive lest the opulence of the Egyptians should inspire them with confidence against the Empire"? Perhaps, thought Bernard, some of these books had escaped destruction. There, in the Greek colony of Alexandria, he would rummage through the scrolls of the ancients.

For four more years he made his pilgrimage. "In this affair," he wrote, "I spent upwards of eleven thousand crowns, and in fact, I was reduced to such poverty that I had but little money left, and yet I was more than sixty-two years of age." Soon he met another monk, who showed him a recipe for whitening pearls. The pearls were etched in the urine of an uncorrupted youth, coated with alum, and left to dry on what remained of the corrosive. Then they were heated in a mixture of mercury and fresh bitch's milk. Bernard watched the process, and behold—the whitest pearls he had ever seen! He was now ready to listen to this skilled adept. Upon security of the last remnant of his once-great estate, he persuaded a merchant to lend him eight thousand florins.

For three years he worked with this friar, treating a rare iron ore with vinegar in the hope of extracting the mystic fluid. He lived day and night in his dirty laboratory, losing his fortune to multiply it. So obsessed was he by this search that he had no time even to wash his hands or his beard. Finally, unable

to eat or drink, he became so haggard and thin that he thought he had been poisoned by some of the deadly fumes in which he had been working. Failure again sapped his health, and the last of his estate was gone.

So alone, friendless, penniless, weary in mind and physically broken, Bernard Trevisan started for his home in Padua, only to find that his family would have nothing to do with him. Still he would not give up the search. Retiring to the Isle of Rhodes, he continued his work with yet another monk who professed to have a clew to the secret. The philosopher's stone remained as elusive as ever! Bernard had spent threescore years grappling with nature; he had lost thousands of crowns; he no longer had the strength even to stand before the furnace. Yet he continued the search.

Once more he returned to the study of the old philosophers. Perhaps he had missed some process in the writings of the ancient alchemists! For ten long years he read and reread every manuscript he could find, until one day he fell asleep and dreamed of a king and a magic fountain. He watched the heavenly bodies robe and disrobe. He could not understand, and in his dream he asked a priest, "What is all this?" and the priest answered: "God made one and ten, one hundred and one thousand, and two hundred thousand, and then multiplied the whole by ten." "But still I do not understand!" cried Bernard. "I will tell you no more," replied the priest, "for I am tired." Then Bernard awoke suddenly. He felt faint and knew the end was near.

I did not think to die
Till I had finished what I had to do
I thought to pierce the eternal secret through
With this my mortal eye.

Grant me another year,
God of my spirit, but a day, to win
Something to satisfy this thirst within.
I would *know* some thing here.
Break for me but one seal that is unbroken.
Speak for me but one word that is unspoken.

But the prayer of the dying alchemist was not answered.

The fire beneath the crucible was out:
The vessels of his mystic art lay round,
Useless and cold as the ambitious hand
That fashioned them, and the small rod,
Familiar to his touch for threescore years,
Lay on the alembic's rim, as if it still
Might vex the elements at its master's will.²

And thus, in 1490, died Bernard Trevisan.

As we peer down the vista of the past we find the delusion of transmutation holding the most prominent place in the minds of thinking men. Frenzied alchemy held the world in its grip for seventeen centuries and more of recorded history. This pseudo-science with its alluring goal and fascinating mysticism dominated the thoughts and actions of thousands. In the records of intellectual aberrations it holds a unique position. Even Roger Bacon of Oxford, easily the most learned man of his age, the monk who seven hundred years ago foresaw such modern scientific inventions as the steamship and the flying machine, believed in the possibility of solving this all-consuming problem.

Sir Isaac Newton, one of the clearest scientific thinkers of all time, bought and consulted books on alchemy as late as the eighteenth century. In his room in Trinity College, Cambridge,

he built a little laboratory where he tried various experiments on transmutation. After leaving the University, he was still concerned with this problem, and wrote to Francis Aston, a friend who was planning a trip through Europe to "observe the products of nature in several places, especially in mines, and if you meet with any transmutation those will be worth your noting. As for particulars these that follow are all that I can now think of. In Schemnitrium, Hungary, they change iron into copper by dissolving the iron in vitriolate water." He was intensely interested in a secret recipe with which a company in London was ready to multiply gold. Robert Boyle, President of the Royal Society, was also so impressed that he helped to procure the repeal of the Act of Parliament against multipliers of gold.

The power and influence of many of the alchemists can hardly be exaggerated. In nearly every court of Europe were men appointed by kings and emperors to transmute base metals, like lead and iron, into gold, and so advance the financial status of their kingdoms. Records exist which tell of the lending of alchemists by one court to another, and of treaties between states where monarchs traded in alchemists. Many were raised to the nobility; many worked shoulder to shoulder with their sovereigns. A number of little houses used as laboratories, situated near the beautiful castle of Emperor Rudolph II in Prague, bear testimony to that monarch's intense interest in this strange science. He neglected the affairs of state to dabble in science, and in Vienna are still displayed leaden bars which Rudolph tried to convert into gold.

Two years before Bernard Trevisan was born, England, by act of Parliament, forbade the making of gold and silver by alchemical processes. Later, however, King Henry IV granted

the right to make gold to certain persons, and at the same time appointed a committee of ten learned men to investigate the possibilities of transmutation. Henry VI went further. He encouraged both the nobility and the clergy to study the science of alchemy, in the hope that they might help him pay the debts of the State. Two soldiers, Edmund de Trafford and Thomas Asheton organized a company which was granted the privilege in 1445 to make the yellow metal and actually produced a product from which coins were minted. When the Scots heard of this English gold, their Parliament refused to allow it to enter their country. Upon analysis, they found it to be an alloy of mercury, copper and gold.

While among the alchemists there were some genuine enthusiasts like Bernard Trevisan, the annals of this queer practice are filled with accounts of charlatans and spurious adepts who, with a deluge of glib words but with only a drop of truth, turned alchemy into one of the greatest popular frauds in history. The writings of these avaricious devils and honest fools are a meaningless jargon of cryptic terms and strange symbols. Their public demonstrations of transmutation were often clever enough to fool the most cautious. Many came to witness the making of gold from lead and iron, convinced that it could be done. For had they not seen iron vessels, plunged into certain natural springs containing copper salts, emerge covered with the red metal? It was a matter of common knowledge that a dark dirty ore could be heated until all its impurities were destroyed and a bright shiny metal was obtained. Traces of silver and gold had been found in many ores. Then why could not the further heating of these ores yield larger quantities of the precious metals? In fact, with sufficient treatment, it ought to be possible to change the ore entirely into lustrous

gold. Simple enough questions in the light of their ignorance of chemical facts. Besides, nature was performing marvelous transmutations every minute of the day as food was changed into blood, and sugar into alcohol. And there were mystics who saw in the change of bread and wine into the body and blood of Christ at the consecration of the elements in the Eucharist a hope that, by the help of God, a similar transmutation could be effected of the baser metals into gold.

In many of the museums of Europe we can still see shiny yellow metals reputed to be gold-products of the deceptions and trickery of the gold cooks of European courts. The Hessian thalers of 1717 were struck from alchemical gold and silver. Some of these samples came from the false bottom of a crucible whose true bottom had been publicly filled with a mysterious mixture which furnace heat was to turn into gold. Other nuggets of gold were gathered from the inside of hollow nails which had been used by impostors to produce gold by "transmutation."

The penalty for failure to produce the philosopher's stone was heavy. For Bernard Trevisan, it meant the loss of an immense fortune, the discouragement of seventy and more years of futile, tireless labor, until death finally came. For many others it was premature death. History records the exposure and punishment of more than one impostor. Marco Bragadino, the gold maker, was hanged by the Elector of Bavaria. William de Krohnemann met the same fate at the hands of the Margrave of Beyreuth. David Benthler cheated the Elector Augustus of Saxony by killing himself. And in 1575 Marie Ziglerin, a female alchemist, was burnt at the stake by Duke Julius of Brunswick. Frederick of Wurtzburg maintained a special gallows, ironically painted in gold, used solely for those unfor-

tunate alchemists who could not fulfill their promises to make real gold. On the gibbet, an inscription had been posted by the hangman for the entertainment of its victim: "I once knew how to fix mercury and now I am fixed myself."

During the summer of 1867 three clever rogues met in Paris: Romualdo Roccatani, a Roman archpriest, Don José Maroto Conde de Fresno y Landres, a Spanish grandee, and Colonel Don Antonio Jimenez de la Rosa, a Neapolitan chevalier. The possessors of these sonorous names had a secret process for turning silver into gold. They were shrewd enough to realize that Emperor Francis Joseph of Austria was, by dynastic tradition at least, keenly interested in alchemy.

Arriving in Vienna they cleverly obtained an audience with the monarch and offered him the most momentous discovery of all time. In Mariposa, California, they told His Majesty, were natural deposits of white nuggets which contained gold formed from silver by the action of mercury and the heat of the sun. They continued: "This same process of transmutation may be brought about much more quickly by artificial methods, through giving the amalgam a specific gravity of 15.47. Thereby a process of nature is imitated when the silver amalgam is exposed to a greatly increased temperature."

Francis Joseph made an initial payment of \$10,000 for the secret, and assigned Professor Schrötter, discoverer of red phosphorus, to supervise a small-scale experiment in the laboratory of the Polytechnic. On October 17, 1867 two iron pots and two glass retorts were filled with silver amalgam and heated for four months. The vessels then cracked. No gold was found. Then, opportunely, the adventurers disappeared, thus cheating the gibbet of three distinguished victims.

Only thirty years ago, in enlightened America, an alchemical

enterprise was started by a Dr. Stephen H. Emmens. This English poet, novelist, logician, chemist, and metallurgist claimed to have discovered "argentaureum," a modern philosopher's stone which could augment the amount of gold in an alloy of gold and silver. Many fanciful stories about this undertaking appeared in the press, even though Dr. Emmens tried earnestly to surround his experiments with strictest secrecy. Much of what appeared in print was deceptive, but this we know—the syndicate formed by the English adventurer sold to the United States Assay Office six ingots of an alloy weighing ten pounds which upon analysis showed the presence of gold and silver. The government paid him the sum of \$954 for the metals, and Dr. Emmens straightway advanced this payment as proof of his astonishing success. For a moment the affair seemed to promise a recrudescence of alchemy. The first dividends were paid, and Emmens even promised a public demonstration at the World Fair in 1900, which, however, never materialized. The whole scheme was a fraud and before long the name of Dr. Emmens was added to that long list of men and women who have gone down in the limbo of the past among the spectacular failures of history.

Alchemy, nourished in superstition and chicanery, still has its adepts and believers. In France, there exists an Alchemical Society for the study of alchemic processes of transmutation. August Strindberg, one of Sweden's great modern literary figures, was a firm believer in transmutation. "People ask me if I can make gold," he wrote, "and I reply, 'to draw the genealogical chart of the ancestors of a cat, I do not have to know how to make a cat.'" He knew, he believed, the secrets of the great riddle, but he never professed to make gold.

In Germany, Franz Tausend, a former plumber, was recently arrested on a charge of having swindled a number of prominent

financiers including General von Ludendorff of more than \$100,000 through asserting that he could make gold synthetically from lead.

From his cell in a jail in Munich, Tausend insisted his discovery was based on modern scientific principles and demanded a chance to show his methods. He was finally taken to the State Mint and in the presence of its Director, two detectives, the State's attorney and the examining judge he began his experiments. Every precaution was taken to prevent fraud: he was minutely searched, all apparatus and chemicals were supplied him from a carefully guarded safe.

The judges watched vigilantly while Tausend worked cleverly with his "tincture of tinctures" made up of lead chloride, and calcium hydroxide smelted with mercury, potassium and sodium. In his second method he used potassium hydroxide, rock flint and ferric oxide.

Then came the official announcement: "After experimenting for two hours Tausend produced a grain of the purest gold weighing one-tenth of a gram which was smelted from 1.67 grams of lead. Experts describe the result as surprisingly favorable and contradictory to scientific knowledge." The cost of production of this alleged synthetic gold was estimated at \$5 per kilogram as against \$700 in the present world market.

The world might have accepted this man and his methods, but the following day the Director of the Mint discovered that, in spite of all the precautions that had been taken, gold which came from the ashes of a cigarette, had been smuggled in to Tausend, and had accounted for the remarkable result. Tausend is back in his prison cell challenging the world to try his process. No doubt the credulous will, for the spell of frenzied alchemy still persists.

What was the significance and value of this strange search

for the philosopher's stone? Was it just a meaningless, childish reaching for the moon? Was alchemy really chemistry as Liebig, one of the world's greatest chemists, believed? Was this long tragedy and farce of alchemy all in vain?

Surely it was not in vain. Francis Bacon compared alchemy "to the man who told his sons he had left them gold buried somewhere in his vineyard; where they by digging found no gold, but by turning up the mould about the roots of the vines, procured a plentiful vintage." In this fanatical search a great mass of valuable discoveries was made, and many chemical facts were learned. Nitric, hydrochloric and sulphuric acids, the three most important acids employed by the modern chemist, and aqua regia, the powerful solvent for gold formed by mixing the first two of these acids were introduced by these early gold searchers. In their quest for the seed of gold in the dirt and dross of centuries, new elements like antimony, arsenic, bismuth and phosphorus were unearthed. Many of the common chemicals of to-day owe their discovery to those early days—alum, borax, cream of tartar, ether, fulminating gold, plaster of Paris, red lead, iron and silver salts and heavy barium sulphate, the first substance known to glow in the dark after exposure to sunlight, stumbled upon by Cascariolo, a cobbler of Bologna.

Some of the apparatus and utensils which are the tools of the chemist of our scientific laboratories were first introduced by alchemists—cupel, distilling flask, retort, water bath and even the balance in its crude form. The extraction of gold by amalgamation with mercury, the preparation of caustic alkali from the ashes of plants, and other new processes of manipulation and methods of manufacture were developed by the gold cooks in their manifold operations.

This heritage is indeed a rich one, for in their blind groping for a new process to make gold these adepts of alchemy paved

the way for the more fruitful science of chemistry. Synthetic gold, however, never came. And as Bernard Trevisan lay dying on the Isle of Rhodes four hundred years ago, he uttered with his last breath his conviction: "To make gold, one must start with gold."

II

PARACELSUS

A CHEMICAL LUTHER FEEDS A BONFIRE

BERNARD TREVISAN was dead. Almost fifty years passed and in front of the University of Basel its students had lit a huge bonfire to celebrate the feast of St. John. Suddenly and unexpectedly appeared Philippus Aurelius Theophrastus Bombast von Hohenheim, lecturer in medicine and chemistry. Under his arm was a copy of Avicenna's *Canon of Medicine*. He turned to his students and ordered brought to him all the books of the old masters of alchemy and medicine which clutched the thoughts of men in a paralyzing grip. "You shall follow me," he shouted, "you Avicenna, Galen, Rhazes, you gentlemen of Paris, Cologne, Vienna, and whomsoever the Rhine and Danube nourish; you likewise Athenians, Arabs, Greeks and Jews, all shall follow me. The latchets of my shoes are better instructed than you all. All the universities, and all the old writers put together are less gifted than the hairs of my beard and the crown of my head."

Then into the flames of the roaring fire he threw the books of the masters, and as the fire consumed these evil scrolls he cried out to his students, "All misery shall be carried away in this smoke."

The world of authority stood aghast. A bonfire had just been kindled by Luther to swallow up the bull of Pope Leo X. And here was another fellow who burned the sacred works of these masters and trampled underfoot every precept they had taught! With the zeal of a religious fanatic and the courage of a cru-

sader, he ran amuck among the treasured beliefs of his day and shattered them in bits. Had they not expected something of the sort from that crazy Paracelsus? Had he not scoffed at their veneration of the Latin tongue, and lectured his students and the crowd of barbers, bathmen and alchemists whom he invited contrary to all precedent, in a racy German? The dons had been horrified. They had warned him about this breach, but he would not be intimidated. What was to be done with such a heretic? He was strongly intrenched at Basel through the influence of Johan Frobenius, the distinguished book publisher of that city to whom he had ministered in sickness, and whose right leg he had actually saved from amputation. Desiderius Erasmus, the great scholar of Rotterdam, was living with Frobenius at the time, and he, too, received medical attention from the Swiss iconoclast who cured him of the gout and kidney trouble. "I cannot offer thee a fee equal to thy art and learning," he wrote to Paracelsus. "Thou hast recalled from the shades Frobenius which is my other half; if thou restorest me also, thou restorest each through the other. May fortune favor that thou remain in Basel."

It was hard to dislodge a man with the spirit of Paracelsus. Three hundred years later Robert Browning revealed in a poem the soul of this sane fanatic. Paracelsus speaks to his friend:

Festus, from childhood I have been possessed
By a fire—by a true fire, or faint or fierce,
As from without some master, so it seemed,
Repressed or urged its current; this but ill
Expresses what I would convey.³

The authorities were afraid of this man who believed himself chosen by God. They waited for a chance to get rid of him.

Besides, Paracelsus had made other enemies. The local doctors hated him. He had denounced them publicly as a "misbegotten crew of approved asses" for their practices of bleeding, bathing and torturing the sick. "The doctors who have got themselves made doctors with money go about the town as if it were a crime for the sick to contradict them," he had told the people. And he sneeringly added, "These calves think themselves great masters, for did they not go through the examination at Nuremberg?"

The apothecaries, too, were enraged against this iconoclast. For had he not, as official town physician, demanded the right to inspect their stocks and rule over their prescriptions which he denounced as "foul broths"? These apothecaries had grown fat on the barbarous prescriptions of the local doctors. "The physician's duty is to heal the sick, not to enrich the apothecaries," he had warned them, and refused to send his patients to them to have prescriptions compounded. He made his own medicines instead, and gave them free to his patients.

All joined in an effort to rid themselves of this firebrand. He was peremptorily ordered to appear before the medical faculty of the University to show cause why he should be permitted to continue to practice medicine in the city of Basel. Frobenius, his patient, had died suddenly and they blamed him for his early death. But Paracelsus knew that death was caused by a stroke due to a strenuous horseback ride to Frankfurt which Frobenius had undertaken against his advice. Paracelsus refused to present himself.

Then they hatched a plot and before long Basel lost Paracelsus, ostensibly because of the meanness of a wealthy citizen. Paracelsus had sued Canon Lichtenfels for failure to pay him one hundred guldens promised for a cure. The patient had offered only six guldens and the fiery Paracelsus, when the

court deliberately handed in a verdict against him, rebuked it in such terms that his life was in imminent danger. In the dead of night, he was persuaded by his friends to leave secretly the city where he had hurled defiance at the pseudo-medicos of the world.

Europe at the time was in the throes of a great intellectual upheaval. Over in Mainz, Johannes Gutenberg introduced printing from movable type. In Eisleben in the heart of Germany, Martin Luther was born to question the orthodox religion of the day and usher in the Protestant Reformation. Columbus, seeking a westward passage to the Indies, discovered a new world. The Polish astronomer, Nicolaus Copernicus, for lack of a telescope, cut slits in the walls of his room in the University of Padua, watched through them the passage of the stars, and then revised man's idea of his place in the universe. Fifteen centuries of Ptolemaic teaching that the earth was the center of the universe, were overthrown. And in Madrid, Andreas Vesalius, another graduate of the University of Padua, raised a storm as he introduced human dissection into the study of anatomy, thereby risking death at the hands of the Spanish Inquisition.

In spite of this renaissance, medicine was still a pseudo-science based on the teachings of Hippocrates of Cos, Avicenna the Persian Prince of Physicians and Galen of Pergamos, gilder of pills and dissector of swine and apes. Superstition, mysticism and false theories were the cornerstones of its structure. Yet so intrenched were these authorities that, even when Paracelsus was still a student at Basel, a certain Dr. Geynes was refused a fellowship at the newly incorporated College of Physicians in England until he had publicly recanted of his error in having doubted the infallibility of Galen the Greek.

Most alchemists and physicians, having failed in their quest

for the philosopher's stone, were now passionately hunting for the universal medicine, a panacea for all the ills of man. "There is nothing which might deliver the body from mortal death," they admitted, "but there is one thing which might postpone decay, renew youth, and prolong human life—the *elixir vitae*." What greater incentive to research could be offered than that strange fluid potent enough to ward off the dreaded encroachments of old age?

Many claimed to have discovered the Grand Catholicon. It is recorded that one man anointed his entire body with it, and lived four hundred years. But failing to anoint his soles he was forced to ride and never walk lest his feet, subject to decay, might bring him premature death. The elixir held forth an alluring promise of perpetual youth and happiness. Need we wonder that the eternal search went on in every corner of the world? Juan Ponce de Leon, landing at Porto Rico soon after the discovery of America, followed the hopeful tales of the Indians and sought the Fountain of Youth only to discover Florida.

This was the world into which Paracelsus was born three years after the death of Trevisan. His father was William Bombast von Hohenheim, a celebrated physician of the little village of Einsiedeln in the Swiss canton of Schwyz. For a while it seemed the child could not survive the weakness of its body. Small, frail and rickety, only the constant care of his mother, in charge of the village hospital, carried him through the dangerous period of infancy.

After attending school in a small lead-mining region where his father was now physician and teacher of alchemy, he was sent for higher instruction to the University of Basel where he adopted the name Paracelsus after Celsius, a famous Roman physician. Here he came across the writings of Abbott Hans



THEOPHRASTUS PARACELSUS

Trithemius, celebrated astrologer, alchemist and inventor of a scheme of shorthand. Influenced by his writings Paracelsus went to Wurtzburg to study under him many books besides the Bible.

Then for a year he worked in the silver mines of Schwatz in the Tyrol. In 1516, at twenty-three, Paracelsus started to "transport himself into a new garden." For nearly ten years he roamed over Europe, matriculating and studying in every famous university. In Paris he met Ambroise Paré, who was learning to tie human arteries, an art which was to bring him fame as the father of modern surgery. This surgeon of King Charles IX was later spared during the slaughter of the Huguenots on the eve of St. Bartholomew's Day. He, like Paracelsus, was the first surgeon to write in his native tongue, nor did he forget to acknowledge his indebtedness to the Swiss reformer.

At Montpellier Paracelsus studied the Moorish system of medicine. He also hovered around Bologna and Padua. Spain and Portugal were included in his itinerary, before he travelled to England. Then the restless spirit of Theophrastus Paracelsus brought him to the Netherlands where war had broken out. He was offered and accepted the post of barber-surgeon in the Dutch Army. Later he served in the same capacity in the Neapolitan Wars during which he came in possession of his famous long sword. He took advantage of his position to attend the Diet of Worms, where he heard his kindred spirit, Luther, make his memorable defense of his doctrines. In Sweden he investigated the causes of mine disasters and studied diseases of miners. The treatment of diseases of horses, goats and cattle occupied much of his time in Russia.

Paracelsus, the crusader, did not stop with Europe. Like Bernard Trevisan, he went to the East and visited Constantinople, the seat of a world-famous medical practice. Trevisan

had come here in search of the secret of gold, but Paracelsus came to seek the secret of long life. He travelled to Egypt and Tartary, and accompanied the son of the Grand Khan in search of the tincture of life possessed by a Greek alchemist.

These years of adventure were years of fruitful experiences. In his passionate search for truth, Paracelsus did not hesitate to mingle with gypsies, conjurers, charlatans, sorcerers, robbers, bandits, convicts, refugees from the law—all manner of rogues and honest men. From them he gathered much curious lore about medicine and alchemy. "My travels," he wrote, "have developed me; no man becomes a master at home, nor finds his teacher behind the stove. Sickneses wander here and there the whole length of the world. If a man wishes to understand them, he must wander too. A doctor must be an alchemist, he must see mother earth where the minerals grow. And as the mountains will not come to him, he must go to the mountains. It is indeed true that those who do not roam have greater possessions than those who do; those who sit behind the stove eat partridge, and those who follow after knowledge eat milk-broth. He who will serve the belly—he will not follow after me."

During these years of travel he studied and practiced medicine and surgery. Students flocked to him in Wurtemberg, Tübingen, and Freiburg. The world began to hear of his wonderful cures. In the meantime Paracelsus was filled with a realization of the wisdom and folly of the medicine of his day. The shams of that pseudo-science kindled in him the fire of a reformer, and when at length he came to Basel as medical lecturer, he was ready for his great battle against the false ideas of healing—a battle which he waged until death found him, before he was fifty, at Salzburg in Austria.

Paracelsus strove to tear away the shackles that enslaved

the human mind to the ancient dogmas of the infallible Avicenna and the categorical Galen. But the authorities at Basel were too powerful. He was forced to leave that city, but not before he had struck a blow at the established leaders of alchemy and medicine from which they never recovered. When he fled from Basel he had already begun his work of destroying age-old tenets. He was still young—only thirty-five. Before leaving his students he made clear to them his plans for the future—"the restoration of true medicine."

Paracelsus, the iatrochemist, found refuge among his friends in Colmar in the province of Alsace whither he called the printer Oporinus, who brought him his chemical apparatus and notes. He set up a laboratory in a cellar and continued to work, but his enemies pursued him. They had styled him the chemical Luther, and, "Why not?" he asked. "Luther is abundantly learned, therefore you hate him and me, but we are at least a match for you."

Paracelsus was bitter. When at Basel they had pinned to the cathedral door a scurrilous attack from the shades of Galen to "Cacophrastus," he had challenged them in no uncertain terms: "Show me what kind of men you are and what strength you have. You are nothing but teachers and masters combing lice and scratching. You are not worthy that a dog shall lift his hind leg against you. Your Prince Galen is in Hell, and if you knew what he wrote me from there you would make the sign of the cross and prepare yourselves to join him. Your dissolute Avicenna, once Prime Minister, is now at the gates of Purgatory. I am preparing 'soluble gold' as a medicine for his suffering." They hated his caustic, vulgar tongue, and with reason.

For thirteen tormenting years Paracelsus led a vagabond life. Driven by poverty and reverses, he devoted his time to writing,

healing and preaching with the energy and passion of one possessed. Like Bernard Trevisan, this Galahad, too, was absorbed in a great search. He was going to crush to the ground every trace of a vicious practice. He was determined to vindicate his teachings before the whole hostile world. The medical reformer met bitter opposition. Innsbruck refused him the privileges of the city. The professors were jealous and the authorities were afraid. He pleased no one but the sick whom he succeeded in healing. Tired, hungry, and in rags, he dragged his sickly body from town to town. He could gain no public hearing, no publisher would print his books; his enemies had seen to that. So for hours at a stretch he would write ceaselessly, and then, too tired to undress, throw himself upon his pauper's bed for a few hours' rest. This outcast was putting down in writing a new message which was to bring the world nearer to a clearer, saner understanding of the art of healing.

Paracelsus shouted the need for experimentation. "I admonish you not to reject the method of experiment, but, according as your power permits, to follow it out without prejudice. For every experiment is like a weapon which must be used according to its peculiar power, as a spear to thrust, a club to strike, so also is it with experiments."

"Obscure diseases," he wrote, "cannot at once be recognized as colors are. What the eyes can see can be judged quickly, but what is hidden from the eyes it is vain to grasp as if it were visible. Thus it is with the obscure and tedious diseases that so hasty judgments cannot be made, though the Galenic physicians do this." And again he attacked the stand-patters. "Do you think that because you have Avicenna of Bukhara, Valescus and de Vigo that you know everything? That which Pliny Secundus and the rest of them have written of herbs they have not tested, they have learned from noble per-

sons and then with their smooth chatter have made books about it. Test it and it is true. You cannot put to proof your authors' writings. You who boast yourselves Doctors are but beginners!"

Those of his followers who believed he always carried the elixir of life with him in the pommel of his famous long sword, attributed his premature death to an overdose of his life-giving fluid or arcanum. His enemies, on the other hand, alleged that his career ended at the hands of an assassin while he was in one of his frequent drunken stupors. It is impossible to credit the first and unfair to believe the second of these stories. To-day we cannot doubt that his end came peacefully. When the time drew near for death to take him, Paracelsus cried:

Let me weep
My youth and its brave hopes, all dead and gone,
In tears which burn. Would I were sure to win
Some startling secret in their stead, a tincture
Of force to flush old age with youth, or breed
Gold, or imprison moonbeams till they change
To opal shafts—only that, hurling it
Indignant back, I might convince myself
My aims remained supreme and pure as ever.

And through the long night, as Browning pictured it, Festus, his friend, comforted this childless man with the assurance that he had not struggled in vain.

When death retires before
Your presence—when the noblest of mankind
Broken in body or subdued in soul,
May through your skill renew their vigor, raise
The shattered frame to pristine stateliness.
When men in racking pain may purchase dreams
Of what delight them most, swooning at once

Into a sea of bliss, or rapt along
As in a flying sphere of turbulent light.
When we may look to you as one ordained
To free the flesh from fell disease, as frees
Our Luther's burning tongue the fettered soul.

Paracelsus took courage. He looked into the future.

But after, they will know me. If I stoop
Into a dark tremendous sea of cloud,
It is but for a time; I press God's lamp
Close to my breast; its splendour, soon or late,
Will pierce the gloom: I shall emerge one day.
You understand me? I have said enough.

Three days before he died, on his forty-eighth birthday, Paracelsus dictated his last will and testament. "There shall be sung in the church," he requested, "the first, seventh, and thirtieth psalms, and at all three singings a penny is to be given in hand to every poor man before the door."

To-day, engraved on a broken pyramid of white marble in the cemetery of the Hospital of St. Sebastian in Salzburg, may be read: "Here is buried Philippus Theophrastus, distinguished Doctor of Medicine, who with wonderful art cured dire wounds, leprosy, gout, dropsy, and other contagious diseases of the body." No mention is made of the elixir of life.

Like Bernard Trevisan, egotistic yet earnest Paracelsus went to his grave beaten in his quest. Years before, he had realized the difficulty of his fight. The old theory of diseases accepted in those days was based upon the conception of Hippocrates of four body fluids or humors—phlegm, blood, yellow bile, and black bile, which in some mystic way were associated with the old Aristotelian elemental qualities—cold,

warm, dry, and moist. Disease was caused by the improper proportions of these four fluids in the body, which also controlled the character of man. An excess of phlegm made one phlegmatic, too much blood made one sanguine, while an abundance of yellow bile produced a choleric person.

Another one of the common beliefs of his day was the doctrine of signatures which dictated the use of certain plants in medicine because their names resembled the part of the body afflicted or the disease itself. The feverwort, for instance, was used to reduce fever, and the liverwort to cure diseases of the liver.

The peculiar practice of sympathetic remedies was prevalent too. A wound was cleaned and then bandaged while the weapon which caused the wound was covered with the remedy. An axe had badly cut a butcher's hand. The bloody hand was washed and bandaged and the axe, covered with the healing salve, was hung on a nail and carefully guarded until the hand was healed. Once, when the butcher suffered very annoying pains, it was found that the axe had fallen from the nail. It was thought that as long as the weapon was watched a magic current through the air would perform the miraculous healing.

For pains in the joints doctors prescribed an oil obtained from the bones of victims of some violent death, and for chickenpox they served their patients a soup filled with the heart and liver of vipers. Against the physicians who professed these ideas Paracelsus had fought all his life. "I shall not in my time," he had written, "be able to overthrow this structure of fables, for they are old and obstinate dogs who will learn nothing new and are ashamed to recognize their folly. That, however, does not matter much, but it does matter that, as I hope, the young men will be of a different character when the old ones have passed away, and will forsake their superstitions."

That day did not come until long after Paracelsus exchanged life for death. The old order survived for decades, and the new order was ushered in only after the old dogmas were safely buried with the dead follies of the past.

The world owes bombastic Paracelsus a great debt. This revolutionist with the imagination of a poet and the fearlessness of a crusader, was much more than the bibulous braggart his enemies had called him. He was a real benefactor of mankind. His great contribution was no one epoch-making discovery, but rather the vital impetus he gave to the study of chemistry for the curing of ills of the body. He swept aside the teachings of the ancient authorities and brought alchemy to the aid of medicine.

"I praise," he told Europe, "the chemical physicians, for they do not go about gorgeous in satins, silks, and velvets, silver daggers hanging at their sides, and white gloves on their hands, but they tend their work at the fire patiently day and night. They do not go promenading, but seek their recreation in the laboratory. They thrust their fingers among the coals into dirt and rubbish and not into golden rings." Here was the true creed of the laboratory. Here alone would mankind find balm for its ills and salvation for its pains.

No longer were the rich to depend upon the playing of the flute to ward off or heal the gout as Galen had taught. Nor was man to rely any more upon the blowing of the trumpet to heal sciatica, as Æsculapius himself had prescribed. Man was no longer to remain captive to the notion that an ape's leg tied around the neck would cure the bite of this beast, nor was medical knowledge to be gained by the scanning of the heavens. And what pernicious nonsense was this singular practice among the old men of Rome of being breathed upon by young girls to prolong their lives!

Paracelsus abandoned all this witchcraft and superstition. He started the search for the potent drugs which the alchemist was to prepare or purify. Even the many herbs and extracts in common medical use were placed secondary to the value of these chemicals. There were many who gave ear to his instructions. They went back to their laboratories, threw away the crucibles filled with the strange concoctions that would not change to gold, and sought medicines to relieve human suffering. Paracelsus himself showed the way. He experimented in his laboratory, and introduced into medicine salves made from the salts of mercury. He was the first to use tincture of opium, named by him laudanum, in the treatment of disease. The present pharmacopœia includes much that Paracelsus employed—lead compounds, iron and zinc salts, arsenic preparations for skin diseases, milk of sulphur, blue vitriol, and other chemicals.

He understood the scepticism of the people about alchemy. Had they not been cheated and duped by those charlatans who claimed to possess the philosopher's stone? "Its name," he pleaded, "will no doubt prevent its being acceptable to many; but why should wise people hate without cause that which some others wantonly misuse? Why hate blue because some clumsy painter uses it? Which would Caesar order to be crucified, the thief or the thing he had stolen? No science can be deservedly held in contempt by one who knows nothing about it. Because you are ignorant of alchemy you are ignorant of the mysteries of nature." The changes which take place in the body are chemical, he said, and the ills of the body must be treated by chemicals. Life is essentially a chemical process and the body a chemical laboratory in which the principles of mercury, salt, and sulphur mingle and react to bring illness or health. Paracelsus believed that if the physician were not skilled to the

highest degree in this alchemy, all his art was in vain. Here was a radical departure from the old practices. It brought to a hopeful close the age of frenzied alchemy, with its search for gold from dung.

Yet the lure of gold was still powerful. In Germany, Christian Rosenkreutz had founded the Brotherhood of the Rosy Cross, which professed to have the secret of making the yellow metal from dew. The Rosicrucians, as they were called, mixed their alchemy with a queer form of religion. Even Paracelsus, while searching for potent drugs to cure the ills of mankind, secretly sought the philosopher's stone, which might yield the cherished gold. Never did he really deny transmutation, and while he shouted from every public forum he was permitted to ascend that "the true use of chemistry is not to make gold but to prepare medicines," we find him privately attempting to prepare alchemic gold.

In his *Coleum Philosophorum* Paracelsus wrote that by the mediation of fire any metal could be generated from mercury. He considered mercury an imperfect metal; it was wanting in coagulation, which was the end of all metals. Up to the half-way point of their generation all metals were liquid mercury, he believed, and gold was simply mercury which had lost its mercurial nature by coagulation. Hence if he could but coagulate mercury sufficiently, he could make gold. And while he tried hundreds of different methods to bring this about, in the end he admitted failure. "From the seed of an onion, an onion springs up, not a rose, a nut, or a lettuce," he declared. The end of his life's journey had brought him to the same secret that Bernard Trevisan had found.

Strange that this modern Paracelsus, called by his followers Life's Dispenser, should have left among his writings such cabalistic directions as these: "Some one may ask, what, then,

is the short and easy way whereby Sol and Luna can be made? The answer is this: After you have made heaven, or the sphere of Saturn, with its life to run over the earth, place it on all the planets so that the portion of Luna may be the smallest. Let all run until heaven or Saturn has entirely disappeared. Then all those planets will remain dead with their old corruptible bodies, having meanwhile obtained another new, perfect and incorruptible body. That body is the spirit of heaven. From it these planets again receive a body and life and live as before. Take this body from the life and the earth. Keep it. It is Sol and Luna. Here you have the Art, clear and entire. If you do not understand it it is well. It is better that it should be kept concealed and not made public." If he intended to conceal his art by clothing it in mystic words, Paracelsus did well, for even if we substitute for Sol and Luna the elements gold and silver, for Saturn lead, and for the other planets the metals mercury, tin, iron and copper, this alchemical jargon becomes hardly more intelligible.

Robert Boyle, one of the founders of modern chemistry, likened such alchemists as Paracelsus to the Argonauts of Solomon's Tarshish who brought home from their long and perilous voyage not only gold, silver, and ivory, but apes and peacocks, "for so the writings present us, together with diverse substantial and noble experiments, theories which either like peacock's feathers make a great show, but are neither solid nor useful, or else like apes, if they have some appearance of being rational, are blemished with some absurdity or other that, when they are attentively considered, makes them appear ridiculous."

And as his writings, so was Paracelsus—strange mixture of honest, fitful, fearless crusader, and mystic, cowardly seeker after gold.

III

BECHER

FIRE IS NOTHING, SOMETHING, LESS THAN NOTHING

ALMOST a century and a half had passed, witnessing the blind efforts of the followers of Paracelsus to bring order out of the chemical chaos. The quest for gold and the elixir of life still occupied the minds and hands of men.

The world wanted gold. Wars had sapped the coffers of the royal families of Europe. A wandering ambitious chemist, physician, economist, and inventor made a tempting proposal to Prince Herman of Baden, who happened to be in Holland. This practical dreamer would make gold from good Dutch sand, and sand was plentiful here. He would make gold, not like the alchemists, by cryptic formulas, but by a practical chemical method which could not fail. He needed hundreds of pounds of silver to change hundreds of tons of sand into mountains of glittering gold. Life had been hard to him and he could not finance this scheme himself. He had already experimented on a small scale in his laboratory in Vienna, whence he had fled after incurring the enmity of the prime minister of Emperor Leopold I. Now he was ready to proceed with his process on a factory scale.

It was 1673 and France was at war with Holland. Prince Herman of Baden could not help him just then, but asked him to return when hostilities had ceased. Becher could not wait, and sought aid from the Dutch Government. His plans sounded plausible enough for the States General to appoint a committee of The Hague to witness a test. He promised the state an in-

come of millions of thalers from this project. These Dutchmen were wary of Becher. They knew the frauds of alchemy. And they did not fail to remind him of the gibbet.

One thirtieth of a million marks was Becher's first request to build a great overshot water-wheel which he had himself invented and patented. This was essential to the success of his plan, Becher insisted, and the committee voted him the equivalent of twelve hundred dollars to start his experiments. The construction of this water-wheel delayed him until December, when he was at last prepared for the decisive trial.

Suddenly he was called away to Mecklenburg at the urgent request of the Grand Duke. This trip was so unexpected and so secretive that it was thought Becher had taken a discreet departure because he knew he could not fulfill his promise. So incensed were the Dutch that one newspaper suggested that he be caught and imprisoned for his frauds. Some of the members of the Committee were ready to withdraw their support.

But Becher returned to silence his enemies. A mind conscious of righteousness, he knew, laughs at the lies of rumor. He started his great experiment at once. A huge furnace was built, and on the 14th of February, 1679, he began the preliminary test in the presence of only one person, Lorenz Keerwolff, who attested to the success of the initial experiment. He had actually changed the white granular sand of Holland into the yellow metal! A month later he repeated his tests in the presence of the select commission of the government and no less a personage than the Mayor of Amsterdam. So cleverly did he work that these experiments, too, were reported to be successful, and he was authorized to continue his work on a larger scale with the assurance that all the necessary funds would be forthcoming. Becher tells us, and this is his own story, that his enemies at Vienna, where at one time he had

been councillor of the Chamber of Commerce, jealous of his epoch-making successes in Holland, intrigued against him. They fomented such trouble among the Dutch Commission that he was in danger of his life, and to save himself he fled hastily, completely abandoning his great work. Kopp, one of the greatest historians of chemistry, says that Becher sought here to make gold "not from greed but as a scientific problem."

At first he found refuge in England, but his enemies discovered his whereabouts and persecuted him. He returned to the Continent, and later Prince Rupert, a nephew of Charles I of England, sent him to the Scottish mines to seek information on a new chemical project in connection with his research on the art of engraving in mezzotint. A terrific storm broke out over the sea, causing his voyage to be held up for four weeks, during which time he wrote *Foolish Wisdom and Wise Folly*. Intermingled with the story of his life, Becher described in this book some of his queer discoveries. He tells us he has seen and handled a heavy stone which rendered its possessor invisible. He relates how Count von Zinzendorf showed him his recipe for making gold. In Scotland he saw geese that grew and lived on trees, and hatched their eggs with their feet. He watched glass being rolled and flattened while cold. His description of a stentrophone conceived by a Mr. Moorland was certainly prophetic of our modern phonograph. This instrument could bottle "several words as an echo through a wire or spiral line, in a flask, so that they could carry this flask about for an hour and when they opened the flask could hear the words."

It was this strange adventurer, John Joachim Becher, born in Speyer, the son of a Lutheran minister, who took a real step forward in the development of modern chemistry by the introduction of the first important theory or generalization. Errone-

ous and deluding though it was, it still held the front of chemical thought for a hundred years.

The ancients considered fire the purest and most perfect of the elements of nature. The flames of fire rose ever upward reaching finally to the highest of the seven heavens—the heaven of fire and light, the empyreum, as they named it. Man's greatest and earliest achievement was the discovery of the use of this fire. The gods had not given this tool to man willingly. It had to be stolen by the demi-god Prometheus who, with the aid of Minerva, ascended to heaven and lit his torch at the chariot of the sun. Fire raised man above the brute. So highly did the ancients regard this luminous spirit that the Egyptians burned a perpetual fire in every temple, and the Greeks and Persians kindled them in every village and town. The Romans consecrated Vestal virgins to watch the sacred fire on their altars.

What is this strange phenomenon called fire? Aristotle considered it one of the great principles of all things. Heraclitus of Ephesus, a Greek philosopher, regarded it not only as the elementary principle of all things, but also as the universal force of creation. In every century men had pondered over the mystery of the flame. The fiery force that could engulf life and bring utter destruction was first regarded with fear and reverence, and later subjected to serious study. Among the ancients, Plato had assumed all burnable bodies to contain some inflammable principle, which, however, he failed to identify. The alchemists of later centuries had considered either some vague spirit of sulphur, or yellow, brittle, solid sulphur itself as the cause of fire. These vaporous concepts they used and discarded at will. Paracelsus explained the burning of wood on the basis of three elements or principles possessed by the wood. It burned because it contained sulphur, it gave off a flame because it had mercury in it, and left an ash because of

the salt that was present in all wood. This explanation persisted for hundreds of years.

Then came Becher, who first enunciated a definite, though pseudo-scientific theory of the nature of fire. Crude though his idea was, it served as a basis of explanation for a great number of chemical phenomena, and gripped the scientific world for more than a century. Priestley, discoverer of oxygen; Scheele, the Swedish apothecary who discovered half a dozen other elements; Cavendish, one of the greatest chemical experimenters of England, all were ardent believers in Becher's conception, not to mention the hundreds of lesser lights in the chemical firmament of the seventeenth and eighteenth centuries. So simple was this theory and so easy to grasp and apply, that it dominated all chemical thought.

Becher's wild and imaginative nature led him into speculations which recall the palmy days of the Middle Ages. Far from being faithful to the spirit of experiment, he arrived at his conclusions outside of his laboratory. Becher threw aside the sulphur principle of his predecessors, for he had found substances which contained no sulphur and yet could burn vigorously. He postulated a "terra pinguis," that is, a fatty or inflammable earth possessed by all substances which could burn. For this fatty inflammable earth he later derived the term "phlogiston," from the Greek, "to set on fire." Phlogiston was fire itself. It was a definite chemical entity of an earthy nature, dry and adapted to solid combination. And it was not to be cast aside wherever it seemed to conflict with observed phenomena. It was to him and his followers the touchstone which explained those great chemical reactions of burning, oxidation, and calcination. The vital processes of breathing could likewise be explained by it, for did not the lungs constantly exhale phlogiston as food was consumed during digestion in human



*Symb. Fidem, Famam, Scientiam,
Pecuniam, Vitam, Tranquilitatem Ipse cura,
neque alius in hac offende.*

IOH. IOACH. BECHERI,
*Medici Chimici & Polyhistoris celeberrimi
effigies aeternam delinquit in Vienna, Austr.
Anno 1578.
Natus Spirae, Nomen tum circa
A.C. 1635.
Obitus Londini in Anglia.*

JOHN JOACHIM BECHER
(Courtesy of Colonel P. M. Asburn, Librarian,
U. S. Army Medical Library)

and animal bodies? When a substance burned, explained Becher, its phlogiston was given off violently in the form of the flame. Weigh the burned body, he said, and you will find that it has actually lost weight in the process, as phlogiston escaped. To him phlogiston was not merely an idea. It was a chemical substance with a definite color, odor, and weight.

But there were doubters even in those days, and some of them experimented while Becher wrote and explained. If phlogiston has weight and leaves the burning body, then the ashes of the burned body should always weigh less than the original substance. So in their crude scales they weighed the ashes of zinc and lead, and found them to have increased in weight! Perhaps these were exceptions, they thought. They repeated their experiments with other metals, and again found that the resulting powders weighed more than the lustrous metals. Here were facts to stump even the wily Becher. They came to him and faced him with the incontrovertible proofs of their crucibles and balances.

But Becher would not acknowledge that his phlogiston had failed as an explanation of burning. "Yes, you fools," he bel-
lowed, "but you do not know that my phlogiston may sometimes possess the power of levity—it weighs less than nothing. Naturally, then, the ash of your metals weighs more than the metals you burned. Something, minus another thing which weighs less than nothing, weighs more than that original something." Cardan, physician and mathematician of Padua, a century before, had attributed the gain in weight of lead to the loss of a similar celestial fire. We laugh at these explanations today, but they were made before the end of the seventeenth century. Chemical science was still struggling to see the light, and natural philosophers were groping in abysmal darkness.

Phlogiston "explained" many facts. Phlogiston was the

same in one metal as in another, as well as in all burnable bodies. When metals were heated or burned they changed into powders or calces, as they were called. Why? Because they surrendered their fire, or phlogiston, to the air. When, however, charcoal, an inflammable substance rich in phlogiston, was added to the calx, the metallic properties were instantly restored. In a similar way phlogiston explained one of the most common of all chemical changes—the rusting of iron. For what was rust, if not iron minus its phlogiston? Add phlogiston to the rust in the form of charcoal, and lustrous metallic iron is re-formed. A simple enough explanation of the metallurgy of iron. Similarly could not the white ash of pure tin be made to yield silvery tin again when phlogiston-rich coal was heated with it? The dead calx of any metal could be instantly restored to life by the addition of Becher's all-powerful phlogiston. Paracelsus, himself, had written, "Dead metals may be revived or reduced (*reduzieren*) to the state of metals by means of soot."

Yet phlogiston was not altogether so simple. There were facts that could not be so neatly explained. For a time it seemed that phlogiston would be discredited. But phlogiston suddenly became chameleon-like, changing its nature to suit each perplexing problem. Lavoisier, who came a hundred years later, spoke thus of phlogiston: "They have turned phlogiston into a vague principle which consequently adapts itself to all the explanations for which it may be required. Sometimes this principle has weight, and sometimes it has not; sometimes it is free and sometimes it is fire combined with the earthly element; sometimes it passes through the pores of vessels and sometimes they are impervious to it. It is a veritable Proteus changing in form at each principle."

Goethe says somewhere that "a pompous word will stand you

instead for that which will not go into the head," and so this mysterious phlogiston, child of the fanciful Becher, nearly destroyed the progress of chemistry when the world of science accepted it as a creed. A number of natural philosophers during the period following Becher caught a glimpse of the true meaning of fire and burning, but Becher's creation had formed a mental smoke screen in front of chemical progress. For almost a century the world struggled through the chemical wilderness, like the Israelites of old before they could see the Promised Land. Had it not been for this blight a Joshua might have risen in the likeness of Boyle, Mayow, or Rey, all of whom had glimpsed the truth behind the veil of fire.

Yet phlogiston did valiant service. It effectively turned the attention of chemists away from the elixir of life and the philosopher's stone to a new field, one which yielded a rich harvest. The challenge of phlogiston led to a more serious study of simple chemical reactions, such as combustion and oxidation, and stimulated the development of the analysis of substances. In this way, "A vigorous error vigorously pursued kept the embryos of truth a-breathing and the body of chemistry was prepared for its soul." ⁴

Alchemy was not altogether dead. A thin feeble blood stream still coursed through its veins. Becher's fertile brain began to wrestle with the mysteries of transmutation, and he proved a worthy and enthusiastic adept. He revelled in its strange secrets.

"The chemists," he wrote, "are a strange class of mortals who seek their pleasures among soot and flame, poisons and poverty, yet among all these evils I seem to live so sweetly that may I die if I would change places with the Persian King." A year after his disastrous efforts in Holland, he published a curious account of the philosopher's stone or "Magnalia Nature," which he claimed had been lately exposed to

public sight and sale. This was supposed to be a true and accurate story of the manner in which Wenceslaus Seilerus, a famous gold cook of the Emperor's court at Vienna, obtained a very great quantity of powder of projection, an esoteric substance akin to the philosopher's stone. The account was published by Becher "at the request and for the satisfaction of several curious persons, especially Mr. Boyle, the eminent English scientist."

The frailties of mankind were the weaknesses of this versatile Becher. When he felt that he was no longer a young man, and fearful that his old age might be a barrier to his advancement, he cut off ten years from his life, and announced his birth date as 1635. Becher, ingenious rogue that he was, went to the extent of secretly inserting in his writings passages to falsify his age. So cleverly did he manipulate this falsehood that twenty of the foremost authorities of the eighteenth century were duped, until it was learned that Da Hayn, who attended the funeral of Becher in 1682, had frequently asked Becher why he claimed to be so young, even though everyone knew he was close to sixty.

Becher inherited from his father some of those qualities which later brought him power. The elder Becher was a teacher at Strassburg and later pastor at Speyer, the seat of the Imperial German Supreme Court and capital of the Bavarian Palatinate. He was a well-educated, forceful man, who, had he not died so early, might have properly directed young John Joachim. At the age of twenty-eight he spoke ten languages well, and wrote some works which unfortunately have not come down to us. If the cultured father wrote well, as we have reason to believe, his son John did not inherit this faculty, for his writings are barbarous both in style and content.

Young Becher's mother remarried, and his stepfather never

spared him the rod. Whatever education he managed to get was obtained with great difficulty. Borrowing or stealing books for which he could not pay, he studied far into the nights, for during the day he worked to help support not only his mother, but his two brothers as well. He managed to earn a little by teaching, and with this he bought other books and acquired a smattering of theology, medicine, chemistry, politics, and law. So far as records show, he spent the equivalent of about eight dollars on elementary education from his teacher Debus—this being his only formal education.

Yet, by dint of a forceful personality, and no doubt, a little rascality, Becher soon began to attract attention. When he met the daughter of the privy-councillor, William von Hornigk, he exclaimed, "The beautiful women have bewitched Samson and Solomon. Why not me also?" After a hasty courtship he was converted to Catholicism and married her. Nothing was to be permitted to stand between him and fame. His marriage and conversion raised him in the estimation of the ruler of Mainz, who made him his personal physician and professor of medicine at the University of Mainz. Becher undoubtedly received his medical degree at the marriage altar rather than at any university—such was the spirit of the times. Drunk with the eminence to which he had been suddenly raised, he was conceited enough to declare that he could learn nothing from the university, since he had learned more by himself. Verily another Paracelsus! Becher kept pushing forward. Charmed by his delightful personality, and awed by his cleverly flaunted erudition, the Elector of Mainz, who had also befriended Leibnitz, the mathematical genius, selected him to compose a universal language for which he was promised one thousand ducats.

Feverishly he worked upon this subject, and the ingenious

brain of Joachim did not rest until he had handed to the Elector a richly bound volume of his universal language, containing no less than ten thousand words. But what had come over the Elector? Someone must have been talking to him about this young upstart. For when Becher handed the manuscript to his patron, instead of the jingle of ducats and the shower of praises, all he could hear was an almost inaudible "Thank you." So embittered was Becher that he was tempted, he tells us, "to send his invention to Pekin, China." So much energy did he put into this work and so disappointed was he at its reception that he developed a high fever, and was so sick at Frankfort that he almost passed away with his universal language. But powerful Becher survived this shock; he was destined to outlive many more.

The problem of perpetual motion was again puzzling the scientists of Germany. Becher heard of it. He was going to put a stop to the perpetual talk of the impossibility of perpetual motion. He, Becher, the brainiest man in all Christendom, was going to prove to the world that a perpetual motion machine could be built. Perhaps the world was not ready for a universal language, he consoled himself. But it could not sit back and scoff at the finished product of a genuine perpetually moving clock. The world was bound to make a beaten path to his door. And while the world waited breathlessly, Becher built his clock.

This clock, which would run on forever without being rewound, needed a firm foundation upon which to rest. Becher prevailed upon the Elector to build a great tower. But a certain employee persuaded Jacob Britzly, the Swiss clockmaker, to tamper with it, so that this costly and artistic work designed for perpetual motion actually resulted in perpetual non-motion or rest. Even the prodigious brain and superhuman skill of a

Becher could not induce a disemboweled clock to run forever. This failure had the desired result. His enemies at the Elector's court, and they were many, had been waiting to expose him and the time had at last arrived. The Elector refused any longer to remain the stupid tool of a lunatic, and Becher was summarily dismissed from his court.

But was he altogether discouraged? Not Becher! A hundred and one more schemes revolved in his restless brain. He would not give up until he had beaten the sceptical world to its feet. He introduced the potato into Germany to feed its swine and cattle and to prevent famine among the poor. He patented a method of distilling coal. He started work on a lamp that would burn forever. He invented weaving and spinning machines. Various mining and metallurgical processes were devised by him. They all ended in commercial disaster. But in spite of his many bankruptcies, there was something about Becher that kept the believing world ready to listen to him once more. His fame as an economist had spread. In 1664 he was called to Mannheim to introduce new manufactures. He was to be given a free hand in the development and enrichment of the city. He planned a new era in the industrial life of that city. He outlined projects for the introduction of the manufacture of glass, paper, and even silk. Silk for the looms was to be obtained from a silk-raising industry which he was to inaugurate. It was an ambitious undertaking.

Before he set his plans in motion, however, he suddenly left for Bavaria. Contracts meant nothing to him. He visioned a greater opportunity. He was to be employed as financial and economic adviser at a very tempting salary, but misfortune still shadowed him. The Bavarian clergy was hostile. Becher had been forced some years before to leave Wurtzburg for performing an illegal operation which resulted in the woman's

death; he could not hide that. The merchants hated him. They could not forget how he had planned to ruin them by building up a government monopoly of cloth manufacture. The nobility, too, was enraged. His schemes seemed to favor the peasant class. His life was secretly threatened if he failed to leave the kingdom. Becher compromised enough to quiet the most powerful of his enemies, and was finally permitted to stay. He founded a silk manufacturing company with money borrowed among the merchants. Soon, however, he left Bavaria to enter the service of Emperor Leopold I. Here at Vienna he prepared to take revenge. He would teach those Bavarians a costly lesson for the way they had plagued him. He built a large silk factory in Vienna and neglected the one in Bavaria, from which he had withdrawn his own funds. Becher chuckled when the news reached him that sericulture in Bavaria had failed dismally.

This restless, ambitious, conceited spirit who had raised himself from poverty and obscurity to the position of Medical Doctor, Privy and Commercial Advisor to His Majesty the Holy Roman Emperor, now turned his hand to another venture. He had written many economic treatises on socialistic and other schemes which gave him a wide reputation. On the strength of this he established an institution for commercial instruction at Vienna, from which he received a salary of the equivalent of ten thousand dollars a year. The four years between 1666 and 1670 were comparatively quiet ones for Becher. While over in England Sir Isaac Newton was discovering the Calculus, Becher was writing his *Physica Subterranea*, by which he is best known in science. In ten days he completed another book, *Methodus Didactica*. His wonderfully equipped laboratory at Munich, the finest in Europe, helped him in his scientific writings. So successful was his *Physica Subterranea*

that it was reissued by his most famous follower, George Ernest Stahl, Professor of Medicine at Halle, and private physician to the King of Prussia.

The spirit of Becher could not long remain tranquil. There were new worlds to conquer. He became involved in an ambitious scheme to unite the whole of devastated Germany commercially by breaking down the numerous tariff walls between the many independent states. Furthermore, various colonization plans were outlined. The Count of Hanau had received three thousand square miles of territory far away in South America from the Holland West India Company. Here, from a tropical jungle between the Amazon and Orinoco Rivers, Becher planned to build up a great fertile plain peopled by his countrymen. The products of this rich soil were to help feed and enrich exhausted Germany. Amid grand festivities and the firing of one hundred cannon, the Hanau West India Company was officially launched—without a single ship. Becher, exultant over his new creation, exclaimed, "We now have a New Germany alongside of New Spain, New France, and New England."

But Germany was to wait for other more successful colonization plans. Becher's brain child proved an abortion; the whole dismal failure was laid at his door. He was accused of mismanagement, theft, and even atheism! Another bubble had burst.

And now Becher was getting old. Fate had dealt harshly with him—everything he touched seemed cursed. The ten years he had tried to slice away from his life hung heavily on his weakened body, and he could no longer hide his fifty-seven years of earthly struggle. He had just returned from the rich mines of Cornwall and the Isle of Wight. While still dreaming of a new world along the Orinoco River and planning great projects which would finally free him from the evil star under

which he was born, suddenly in 1682 he died in poverty in London. Reverting to Protestantism before he died, he was buried in the chancel of St. James-in-the-Fields, in London.

Becher's span of life covered a period of intense intellectual activity. Harvey, in England, was demonstrating with remarkable precision the circulation of the blood. Hooke was writing *Micrographia*, a book on microscopy which Samuel Pepys, famous diarist and President of the newly founded Royal Society of England; read with great delight. Roemer, a Dane, was measuring the speed of light. Torricelli, in Italy, was demonstrating atmospheric pressure with his newly invented barometer. Von Guericke, burgomaster of Magdeburg, was introducing the air-pump and astonishing the Emperor and his court as sixteen pairs of horses struggled in vain to pull apart two hollow iron hemispheres from which the air had been exhausted. Anthony van Leeuwenhoek, in Holland, was gazing upon red blood corpuscles and minute plants and animals under microscopes which he himself constructed, while Huygens, his compatriot, was inventing a pendulum clock, and Spinoza, the lens grinder of Amsterdam, was writing his *Ethics*. Descartes, the French philosopher, was enriching the sciences of mathematics and physics in many of their branches.

In the field of chemistry, too, there was great animation. Nicholas Lemery was publishing his *Cours de Chimie*. Johann Glauber in Bavaria was discovering important chemical salts and publishing an encyclopedia of chemical processes. Rey, a French physician, was writing a curious account of experiments on the rusts of tin and lead. John Mayow, of Cornwall, another physician, was investigating the respiration of animals in air and its relation to the burning of metals. And in the same year that Becher published his *Physica Subterranea*,

Brandt, a Hamburg merchant and alchemist, accidentally discovered fiery phosphorus which shone in the dark, and awakened the curiosity of the world with his cold fire. While Krafft, who had learned the secret from Brandt, made a tour of the Continent exhibiting glowing phosphorus to the crowned heads of Europe, immortal Newton sat before a large tub of soap suds, blowing bubbles through a common clay pipe and watching their colors in the bright sun—the same Isaac Newton who was giving to the world one of the greatest scientific contributions of all times, the theory of gravitation.

Becher had travelled widely through Sweden, Italy, Holland, France, and other countries. He knew many of these illustrious scientists and philosophers. He read voluminously, was familiar with the literature of chemistry, and never failed in his writings to quote the opinions of others. His only lasting contribution to applied chemistry, however, was his experimental discovery of the gas ethylene, recently introduced by Dr. Lockhardt as an anesthetic, which Becher prepared by the action of common alcohol on sulphuric acid.

Stripped of the many-sided ambitious projects which occupied the greater part of his tempestuous life, Becher stands out as the pioneer of a new path over which chemistry was thenceforth to travel. Chemistry was again at the crossroads, and it was Becher who pointed the way. Although phlogiston contained the germ of the old fire principle of Zoroaster, and, like the subtle ether of to-day, was based upon conjecture rather than experimentation, still it drew men to more practical endeavors. Becher gave phlogiston to the world "clothed in such a material garb that it required two centuries to unwrap the truth. Still the sparkle of the gem was there, and men followed it until it led them into a clearer day." ⁵

A hundred years after Becher's death, Madame Lavoisier, robed as a priestess, and surrounded by the scientific celebrities of Paris, burned his writings with those of his illustrious follower, Stahl, upon an altar. And, as a solemn requiem was chanted, the theory of phlogiston perished in France, while out of its ashes, like the Phœnix of old, sprang up a new chemistry.

IV

PRIESTLEY

A MINISTER FINDS THE PABULUM OF LIFE

BECHER lies buried in his grave for a century. Great political upheavals have shaken the foundation of Europe and institutions have gone tumbling to the ground. The French have stormed their Bastille in Paris while eager, greedy, curious men pottered around in smoky laboratories ever seeking to unravel some of the secrets of nature.

The anniversary of the storming of the Bastille is approaching. Over in Birmingham, England, liberal men are planning to celebrate this historic day. Modestly, quietly, without drum-beat or torch-light, they gather in the meeting-house of the town. Among these lovers of human freedom is a dissenting minister, named Joseph Priestley, who, too, has joined this group to commemorate the emancipation of a neighboring nation from tyranny.

It is July 14, 1791. Outside the meeting-place two men on horseback are stationed in front of a wild mob. One of them is reading a long document, prepared by an agent of the King: "The Presbyterians intend to rise. They are planning to burn down the Church. They will blow up the Parliament. They are planning a great insurrection like that in France. The King's head will be cut off, and dangled before you. Damn it! you see they will destroy us! We must ourselves crush them before it is too late." The cry of Church and King goes up and a thousand men break loose. And as the magistrates of the city

look on and applaud, Priestley's meeting-house is burned to the ground.

The clergy all over England had inflamed the people against the Dissenters. Priestley was also an enemy of the government party. He had been a thorn in its side for years. Openly siding with the American colonists in their struggle for independence, he had brazenly broadcast letters like the following which Benjamin Franklin had sent him. "Britain, at the expense of three millions," wrote the candle-maker's son from Philadelphia, "has killed one hundred and fifty Yankees this campaign, which is twenty thousand pounds a head; and at Bunker's Hill she gained a mile of ground, half of which she lost again by our taking post on Ploughed Hill. During the same time sixty thousand children have been born in America. From these data your mathematical head will easily calculate the time and expense necessary to kill us all, and conquer the whole of our territory."

He was fearless in espousing any cause which seemed just to him. He had just been made a citizen of the French Republic for publishing a caustic reply to Burke's attack on the French Revolution. To this dangerous agitator's home the crowd rushed, demolished his library, smashed to bits all his scientific apparatus, and burned his manuscripts. Priestley was not the only victim. The residence of Dr. Withering was also attacked and the homes of others of Priestley's friends were pillaged and burned, while some of the Dissenters, to escape the terror, scrawled "No Philosophers" on their doorsteps. Still the fury of the mob was not abated. "Let's shake some powder out of Priestley's wig," yelled one rioter, and away they went to hunt him out. But the stuttering minister had been warned, and he fled to London, while for three days the riot continued, encouraged by some members of the court of King George III, who thought to intimidate the friends of liberty by this means.

After his flight to London, Priestley found himself much restricted with respect to philosophical acquaintances. In Birmingham since 1780 he had been the center of a stimulating intellectual circle. He had infused new vigor into this small group of men who called themselves the Lunar Society because they were accustomed to dine once a month near the time of the full moon, "so as to have the benefit of the light on returning home" as Priestley explained. Erasmus Darwin, grandfather of Charles Darwin, was its patriarch. As this portly gentleman with his scratch-wigged head buried in his massive shoulders stammered out his lively anecdotes, the room fairly rocked with laughter. On one occasion, finding himself unable to attend a meeting he wrote: "Lord, what inventions, what wit, what rhetoric, metaphysical, mechanical and pyrotechnical will be on the wing—while I, I by myself I, am joggled along the King's highway to make war upon a stomach-ache."

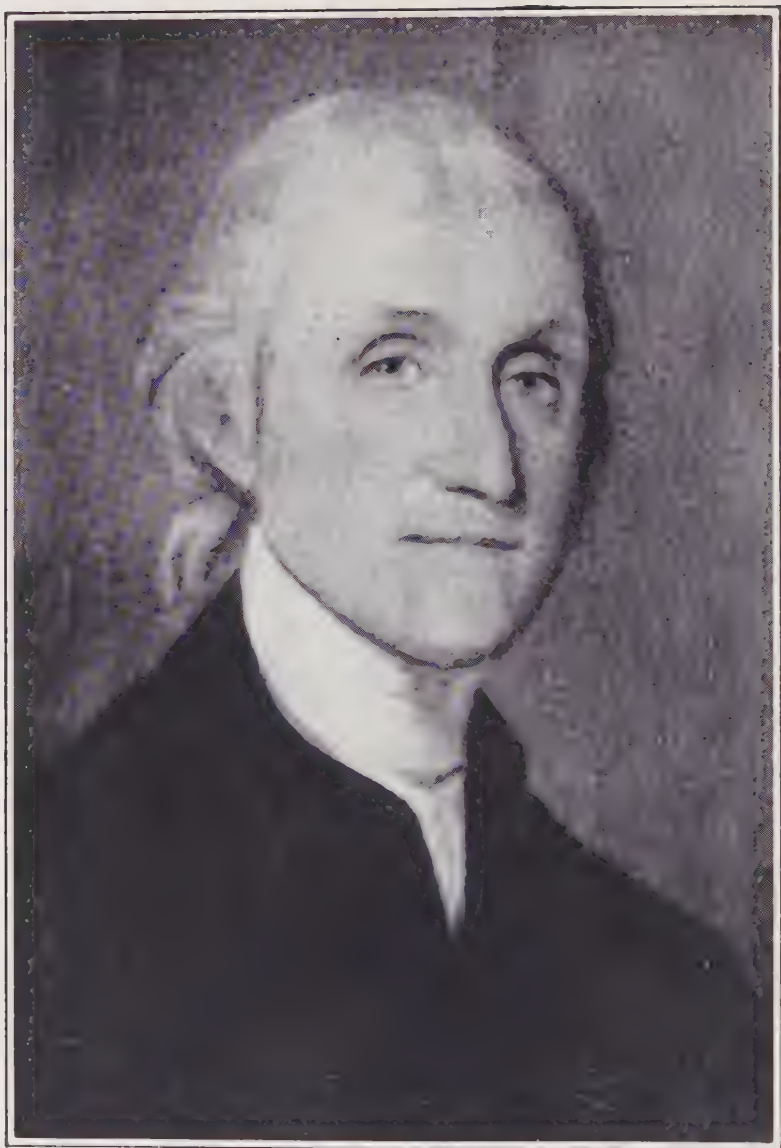
James Watt, celebrated Scotch engineer and perfecter of the first practical steam-engine sat there with his business partner, Boulton, while Samuel Galton, wealthy man of letters, exchanged views on science, literature and politics with Dr. Withering, physician and chemist. Captain James Kerr, commercial chemist and author; Collins, an American rebel, and Dr. Henry Moyes, a blind lecturer in chemistry, completed this brilliant gathering among which Joseph Priestley "seemed present with God by recollection and with man by cheerfulness."

Priestley missed this social and intellectual life deeply, for most of the members of the Royal Society shunned him either for religious or for political reasons. When London's natural philosophers met once a week at Jacob's Coffee House with Sir Joseph Banks, Sir Charles Blagden, Captain Cook and Dr. George Fordyce, Priestley was not a welcome visitor. Finally

he resigned from that scientific body. More than a century later during the World War, on similar grounds, the scientists of Germany struck the names of England's most eminent chemists from their list of foreign honorary members. Such is the madness of men, even among scientists, in times of stress.

And while over in France, the Department of Orne was electing this son of a poor dresser of woolen cloth member of its National Convention, he brought action for damages to the extent of four thousand pounds against the city of Birmingham. King George wrote to Secretary Dundee: "I cannot but feel pleased that Priestley is the sufferer for the doctrines he and his party have instilled, yet I cannot approve of their having employed such atrocious means of showing their contempt." The case went to a jury and after nine hours Priestley triumphed. The great wrong done was in part righted, and Priestley was enabled again to give himself to the world of science.

Born in 1733 at Fieldhead, near Leeds, of staunch Calvinists, Priestley was prepared for the ministry. At the age of twenty-two, after having been rejected because of his views on original sin and eternal damnation, he was appointed pastor of a small chapel in Suffolk, earning thirty pounds a year. Much as he was averse to teaching, he was compelled by his meager salary to do so. This master of French, Italian, German, Arabic, Syriac, and even Chaldee, between seven in the morning and four in the afternoon taught school; between four and seven, he gave private lessons; and then, whatever time he could snatch from his clerical duties he devoted to the writing of an English grammar. A few years later Priestley, while teaching languages in an academy established by Dissenters at Warrington, attended a few lectures in elementary chemistry, studied anatomy for a while, and attempted a course of lectures in this subject.



JOSEPH PRIESTLEY

Then at the age of thirty-four, Priestley went to take charge of the Mill Hill Chapel at Leeds. Poor, struggling to support a family on the scantiest of means, unpopular because of his religious views, and, like Demosthenes, battling a serious defect in his speech, this many-sided Englishman found time between his theological duties and metaphysical dreamings for more worldly matters. During one of his occasional trips to London he met Benjamin Franklin, who stirred in him an interest in electricity. Priestley planned to write a history of this subject with books and pamphlets which Franklin undertook to supply. This was the beginning of his career as a scientist. "I was led in the course of my writing this history," he tells us, "to endeavor to ascertain several facts which were disputed, and this led me by degrees into a larger field of original experiments in which I spared no expense that I could possibly furnish."

Some part of the fame which is Priestley's was due to the public brewery which adjoined his home here in Leeds. In this smelly factory he busied himself in his spare moments, experimenting with the gas which bubbles off in the huge vats during the process of beer-making. He lighted chips of wood and brought them near these bubbles of colorless gas as they burst over the fermenting beer. It was a queer business for a minister, and the factory hands shook their heads as they watched him bending over the bubbling cisterns that hot midsummer. Priestley was too absorbed to pay any attention to their stifled laughs. He knew little chemistry, but he was a careful observer. He noticed that this colorless gas had the power of extinguishing his burning chips of wood. He suspected that it might be the same "fixed air" which fifteen years before Joseph Black, son of a Scotch wine merchant, had obtained by heating limestone while on the trail of a secret remedy of calcined snails

by means of which a Mrs. Joanna Stephens had cured the gout of Robert Walpole, England's Prime Minister. Could this be true? Unable to obtain sufficiently large quantities of this gas from the brewery, he learned to prepare it at home. He tried dissolving the gas in water. It was not very soluble, but some of it did mix with the water. In this manner in the space of two or three minutes he made, as he related, "a glass of exceedingly pleasant sparkling water which could hardly be distinguished from Seltzer water." Appearing before the Royal Society he told that learned body of his discovery of what we now know as soda water—a very weak acid solution of carbon dioxide gas in water. The Royal Society was intensely interested, and he was asked to repeat his experiments before the members of the College of Physicians. He jumped at the opportunity, and as he bubbled the gas through water, he asked some of those present to taste the solution. They were very much impressed, and recommended it to the Lords of the Admiralty as a possible cure for sea scurvy. Priestley received the Society's gold medal for this discovery, the first triumph of this amateur chemist in science.

Priestley, the dilettante scientist, was happy. He busied himself with other chemical experiments. What a relief to get away from his ministerial duties and lose himself in this great hobby! He tried heating common salt with vitriolic acid, and obtained a product which others had missed, for Priestley collected the resulting gas over liquid mercury rather than over water, as his predecessors had done. The colorless gas which he obtained had a pungent, irritating odor. He tried to dissolve it in water. Hundreds of volumes of this gas were easily dissolved—the water sucked it up greedily. No wonder the gas had not been collected before! It had dissolved in the water over which they had tried to imprison it. This gas dissolved

in water is the hydrochloric acid used extensively to-day as muriatic acid (Priestley's name) for cleaning metals and in the manufacture of glue and gelatine. Here was another great contribution to chemistry by this mere amateur.

The Rev. Joseph Priestley's congregation was puzzled at his abiding interest in bottles and flasks. He seemed to be serving two altars. There was some grumbling, but the English minister was too excited to listen. He was now heating ammonia water and collecting another colorless gas over mercury. This gas, too, had a characteristic irritating odor. The fumes filled his room as he bent over the logs of the open fireplace, stirring the embers into greater activity. He was giving science its first accurate knowledge of the preparation and properties of pure ammonia—the gas which has been so successfully employed in refrigeration. What if the vapors did make his eyes tear until he was almost blinded, and drove the occupants of his humble house into the open to catch their breaths? This thrilled him more than any passage in the Scriptures. Then Priestley brought these two dry, colorless, disagreeable gases, hydrogen chloride and ammonia, together. He was amazed at the result. The gases suddenly disappeared and in their place was formed a beautiful white cloud which gradually settled out as a fine white powder. A great chemical change had taken place—a deep-seated change. Two pungent gases had united to form an odorless white powder—ammonium chloride, now used as an electrolyte in the dry battery.

Thus in the space of a few years Priestley, eager devotee of science made a number of significant discoveries. He began to spend more and more time in his makeshift laboratory. Chemistry had completely captivated him. And as he spread the word of God among his worshipers in Leeds, the world of science, too, began to hear of this preacher-chemist. Soon a

proposal came to him to accompany Captain James Cook on his second voyage to the South Seas. He was tempted but, fortunately, another clergyman objected to him because of his religious principles. He stayed behind, and continued the great experiment that was to bring him lasting fame.

Priestley's experiments with the different kinds of gases or airs, as he called them, had made him very proficient in the preparation and collection of these elastic fluids. Until his time, the various gases had been studied by collecting them first in balloon-like bladders. This was a clumsy method, and besides, the bladders were not transparent. Priestley introduced and developed the simple modern method of collecting gases. He filled a glass bottle with liquid mercury, and inverted it over a larger vessel of mercury, so that the mouth of the bottle was below the quicksilver in the vessel. A tube was connected, by means of a cork, to the gas generator, and the end of this delivery tube was placed under the mouth of the bottle of mercury. The escaping gas displaced the mercury in the bottle, and was thus imprisoned in a strong transparent container. For those gases which are insoluble in water, Priestley used water, lighter and much less expensive than mercury, in the glass bottle and trough, even as Hales and Mayow had done before him. Here was a decided advance in the methods of studying gases.⁶

Priestley had heated a large number of solid substances in the flames of his furnace. Now he tried utilizing the heat of the sun by means of a sun-glass. By concentrating the sun's rays upon a burning lens, he found that he could obtain a sufficient heat to burn wood and other solid materials. Finally he procured a very large lens, a foot in diameter, and proceeded with great alacrity to heat a great variety of substances both natural and artificial. He placed the solid substances in a bell-jar arranged

so that any gas which might be formed inside of it would pass out and be collected in a bottle placed over a trough of mercury. The burning lens was so placed outside the bell-jar that the heat of the sun was concentrated upon the solid to be tested. With this apparatus, he endeavored, on Sunday the first of August, 1774, "to extract air from *mercurus calcinatus per se*," a red powder known to Geber and made by heating mercury in the air. "I presently found," he reported, "that air was expelled from it readily."

But there was nothing startling about this. Others before him had obtained gases by heating solids. Scheele, the great Swedish apothecary chemist, had obtained the same result three years before by collecting "empyreal" air. Robert Boyle, a hundred years back, had heated the same red powder and obtained the same mercury. Stephen Hales, too, had liberated a gas from saltpetre but saw no connection between it and air. Eck of Salzbach, an alchemist, had likewise performed this experiment three centuries before in Germany, and yet the world had not been aroused, for nothing further had been discovered about the gas.

A lighted candle was burning in Priestley's laboratory near him. He wondered what effect the gas might have on the flame of this candle. Merely as a chance experiment, he placed the candle in a bottle of the gas. The flame was not extinguished. On the contrary, it burned larger and with greater splendor. He was thrilled with excitement but was utterly at a loss to account for this phenomenon. He inserted a piece of glowing charcoal in another bottle of this gas, and saw it sparkle and crackle exactly like paper dipped in a solution of nitre. The burning charcoal was quickly consumed. He was astounded. He inserted a red hot iron wire. The heated metal glowed and blazed like a spirit possessed. The preacher's agitation knew no bounds.

This chance insertion of the lighted candle ushered in a revolution in chemistry. Speaking about this memorable occasion some years later, Priestley said, "I cannot at this distance of time recollect what it was that I had in view in making this experiment; but I had no expectation of the real issue of it. If I had not happened to have a lighted candle before me, I should probably never have made the trial, and the whole train of my future experiments relating to this kind of air might have been prevented. . . . More is owing to what we call chance than to any proper design or preconceived theory."

At this time Priestley had no notion of the real nature of this air. He was steeped in the fire principle of Becher and believed the gas to be, not the simple substance we know to-day as oxygen, but some strange compound of phlogiston, earth, and nitric acid—so completely had phlogiston befuddled him. But he kept studying this mysteriously active gas which had been driven out of his red powder. Fumbling along as best he could, hampered by meager funds, a poor foundation in chemistry, and no clear goal before him, he continued to investigate the properties of this gas. Once before, he had accidentally prepared it from saltpetre, but had neglected to carry out any further experiments with it. The perfect scientist would have probed into the character of this gas as soon as he had prepared it, but Priestley was not the perfect experimenter.

At that time, the atmosphere we breathe was thought to be a pure, simple, elementary substance like gold or mercury. Priestley himself had first conjectured that volcanoes had given birth to this atmosphere by supplying the earth with a permanent air, first inflammable, later deprived of its inflammability by agitation in water, and finally purified by the growth of vegetation. He had concluded that the vegetable world was nature's supreme restorative, for when plants were placed in sealed

bottles in which animals had breathed or candles had been burned, he had noticed that the air within them was again fit for respiration. The phlogiston, he thought, which had been added to the atmosphere by burning bodies, was taken up by plants, thus helping to keep the atmosphere pure. But just about this time Daniel Rutherford, a medical man who occupied the chair of botany at the University of Edinburgh, had found two substances in the air. He had absorbed a small amount of carbon dioxide from the air, by means of lime-water, which turned milky white. Then, by allowing a small animal to breathe in a limited supply of air, he found that after the carbon dioxide had been absorbed, about four-fifths of the volume was left in the form of an inert gas. This inactive gas of the air was named by Chaptal *nitrogen*, because of its presence in nitre.

Priestley had read of these experiments. He began to suspect something. He heated some lead very strongly in the air and watched it gradually turn red. This red powder he treated in exactly the same way that he had heated the red powder of mercury. Priestley danced with glee, for he had obtained the same oxygen! He was confirmed in his suspicions that this oxygen which he had obtained both from the red powder of mercury and the red lead, must have originally come from the atmosphere. "Perhaps it is this air which accounts for the vital powers of the atmosphere," thought Priestley. "I shall find out how wholesome is this dephlogisticated air."

On the eighth of March, 1775, we find this honest, religious heretic working on a queer experiment in the large castle of Lord Shelburne in Bowood near Calne. The night before he had set traps for mice in small wire cages from which the animals could be easily removed alive. But what is this moulder of the souls of men to do with mice? They are going to unravel a mystery for him. He takes two identical glass vessels, fills one

with oxygen and the other with ordinary common air, and sets them aside over water.

The next morning he removes one of his captive mice from the trap, takes it by the back of the neck and quickly passes it up into the vessel of common air inverted over water. He sets the mouse on a raised platform within the vessel, out of reach of the water. The little beast must not drown. Then under the second vessel, filled with oxygen, he places an equally vivacious mouse with the same care:

Seated on a chair, Priestley amuses himself by playing the flute as he watches his curious experiments. He has no idea how long he will have to wait. Suddenly he stops playing. The mouse entrapped in the glass vessel containing common air begins to show signs of uneasiness and fatigue. Priestley throws away his flute and looks at his clock. Within fifteen minutes the mouse is unconscious. Priestley seizes its tail, and quickly yet carefully pulls it out of its prison. Too late—the mouse is dead. He peers into the second vessel containing his oxygen. What is happening to its tiny inmate? Nothing alarming. It keeps moving about quite actively. Ten minutes more pass. Priestley is still watching the animal. It begins to show unmistakable signs of fatigue. Its movements become sluggish—a stupor comes over it. The minister rushes to set it free, and takes it out of its tomb apparently dead. It is exceedingly chilled, but its heart is still beating. Priestley is happy. He rushes to the fire, holds the little mouse to the heat, and watches it slowly revive. In a few minutes it is as active as ever. He is unable to believe his senses. For thirty minutes this animal has remained in his oxygen and survived, while the first mouse, confined in common air, had died in half that time!

What can account for this? Is it possible that his oxygen is purer than common air, or does common air contain some

constituent which is deadly to life? Perhaps it is all an accident. That night Priestley keeps pondering over the mice and his oxygen. He begins to suspect that his oxygen is at least as good as common air, but he does "not certainly conclude that it was any better, because though one mouse might live only a quarter of an hour in a given quantity of air, I knew," he told himself, "it was not impossible but that another mouse might have lived in it half an hour." And the next morning finds Priestley experimenting with more mice to probe this mystery of the air.

He looks for the glass vessel in which a mouse had survived fully thirty minutes the day before. He is in luck. The vessel still contains oxygen. He is going to use this air over again, even though it has been rendered impure by the breathing of the mouse. He thinks of putting two or three mice in this vessel but abandons the idea. He has read of an instance of a mouse tearing another almost to pieces, in spite of the presence of plenty of provisions for both. So he takes a single mouse and passes it up on to its floating platform. He watches it intently for thirty minutes while it remains perfectly at ease. But slowly it passes into a slumber, and, "not having taken care to set the vessel in a warm place, the mouse died of cold. However, as it had lived three times as long as it could probably have lived in the same quantity of common air, I did not think it necessary," wrote Priestley, "to make any more experiments with mice."

Priestley was now convinced of the wholesomeness of his oxygen. The mice had proved this to him beyond doubt. He might have ended his experiments at this point, but he had the curiosity of the true natural philosopher. He decided to substitute himself for his humble mice, and partake of this gaseous pabulum of life. Breathing strange gases was a dangerous busi-

ness but Dr. Mayow, a hundred years before him, had found that a certain gas (nitro-aerial spirit obtained by him from nitre) when breathed in the lungs gave the red color to arterial blood. Priestley wondered if his oxygen would be just as effective. He inhaled some freshly prepared oxygen through a glass tube, and found to his astonishment that the feeling in his lungs was not sensibly different from that of common air, "but I fancied," he noted, "that my breath felt peculiarly light and easy for some time afterward. Who can tell but that in time this pure air may become a fashionable article in luxury. Hitherto only my mice and myself have had the privilege of breathing it." Priestley foresaw many practical applications of this very active gas—"it may be peculiarly salutary to the lungs in certain morbid cases when" (as he explained it in his terms of phlogiston) "the common air would not be sufficient to carry off the phlogistic putrid effluvium fast enough." To-day pure oxygen is, in fact, administered in cases of pneumonia where the lungs have been reduced in size and the patient cannot breathe sufficient oxygen from the air. Firemen fighting suffocating fumes, rescue parties entering mines, aviators and mountain climbers, who reach altitudes where the air is very rare, carry tanks of pure oxygen.

Priestley, the tyro, more than a century and a half ago had dreamed of these modern practical uses of oxygen. Priestley, the minister, also saw a possible danger of using this gas constantly instead of common air, "For as a candle burns out much faster in this air than in common air, so we might *live out too fast*. A moralist at least may say that the air which nature has provided for us is as good as we deserve."

Priestley kept testing the purity of his newly discovered gas. He found it to be "even between five and six times as good as the best common air" that he had ever handled. His imaginative

mind was often very practical, and again he thought of a possible application of this oxygen. He saw in it a means of augmenting the force of fire to a prodigious degree by blowing it with his pure oxygen instead of common air. He tried this in the presence of his friend Magellan by filling a bladder with oxygen and puffing it through a small glass tube upon a piece of lighted wood. The feeble flame burst at once into a vigorous fire. Here was the germ of the modern blow-pipe which uses yearly three billion cubic feet of oxygen for cutting and welding. He even suggested that it would be easy to supply a pair of bellows with it from a large reservoir, but left to Robert Hare, of Philadelphia, the actual invention of the oxy-hydrogen torch.

The results of his experiments set Priestley all a-quiver. A few weeks later Lord Shelburne, who had shared his views regarding the American Colonists, took a trip to the Continent. This scholarly statesman had offered Priestley an annuity of two hundred and fifty pounds, a summer residence at Calne, and a winter home in London, to live with him as his librarian and literary companion. For eight years this beautiful relationship lasted, and it was during these years that Priestley performed his most productive experiments. On this trip to the Continent, Priestley accompanied his patron. While in Paris, Priestley was introduced by Magellan, a descendant of the circumnavigator of the globe, to most of the famous chemists of France. In Lavoisier's laboratory, in the presence of a number of natural philosophers, he mentioned some of the startling results of his experiments. Lavoisier himself honored him with his notice, and while dining with him Priestley made no secret of anything he had observed during his years of experimentation, "having no idea at that time to what these remarkable facts would lead." Lavoisier listened to every word of this

Englishman, and when Priestley left to visit Mr. Cadet, from whom he was to secure a very pure sample of the red mercury powder, Lavoisier went back to his laboratory, lit the fire of his furnace, and repeated the experiments of the minister.

Now Priestley was back in England, little dreaming to what his meeting with Lavoisier was to lead. To Priestley the atmosphere was no longer a simple elementary substance. The riddle of the air was already on the threshold of solution when Priestley was born. The Chinese, many centuries before, had written of "yin," the active component of the air which combined with sulphur and some metals. Leonardo da Vinci, that versatile genius of Italy, had been convinced back in the fifteenth century of two substances in the air. Others, too, had caught faint glimpses of the true nature of the atmosphere. Yet it was Priestley who, by the magic of chemistry, called up invisible oxygen from the air and first solved, by his discovery of this most abundant element of the earth, the profound enigma of the atmosphere. This puzzle, so simple to-day that few cannot answer it, so important that its mystery impeded the progress of chemistry for centuries, was finally solved by this man who typifies the intellectual energy of his century. To this heretic of the church, chemistry was but a hobby, a plaything that filled the spare moments of his varied life. Out of this almost juvenile pursuit came the unravelling of one of the world's great mysteries. Priestley's discovery of oxygen marked a turning point in the history of chemistry.

On August 1, 1874, there was celebrated in Birmingham, England, the centennial of this great discovery. A statue of Priestley was to be unveiled. Three thousand miles away, in America, a cablegram was dispatched by a group of American chemists gathered in a little graveyard in Northumberland, Pennsylvania, on the banks of the Susquehanna River. Dr.

Joseph Priestley, a great-grandson of the English scientist, was present to witness the ceremonies in honor of his illustrious ancestor. For Priestly had been buried in America.

He had come to the New World when conditions in England became unbearable for him. The press had attacked him, and Edmund Burke had assailed him on the floor of the House of Commons for championing the cause of the French revolutionists. Finally, when his scientific friends began to snub him, Priestley, though past sixty, decided to come to America. His landing in New York was like the arrival of a conquering hero. His fame as theologian, scientist, and liberal had spread to the Colonies. Governor George Clinton and Dr. Samuel Mitchill, of Columbia University, a former pupil of the celebrated Dr. Black, of Edinburgh, were among the distinguished citizens who met him at the pier. The Tammany Society of New York, "a numerous body of freemen who associate to cultivate among them the love of liberty," sent a committee to express their pleasure and congratulations on his safe arrival in this country. "Our venerable ancestors," they told him, "escaped as you have done from the persecution of intolerance, bigotry, and despotism. You have fled from the rude arm of violence, from the flames of bigotry, from the rod of lawless power, and you shall find refuge in the bosom of freedom, of peace, and of Americans."

When Priestley left for America on the 7th of April, 1794, there were many Englishmen who realized their country's loss. The Rev. Robert Garnham expressed this misfortune in verse:

The savage, slavish Britain now no more
Deserves this patriot's steps to print her shore.
Despots, and leagues, and armies overthrown,
France would exult to claim her for her own.

Yet no! America, whose soul aspires
To warm her sons with Europe's brightest fires,
Whose virtue, science, scorns a second prize,
Asks and obtains our Priestley from the skies.

America did more than greet this slender, active man with flattering phrases. The Unitarian Church offered him its ministry. The University of Pennsylvania was ready to make him professor of chemistry. Other offers of speaking tours and the like came to him. He accepted none. Benjamin Franklin had made great efforts to have him settle in Philadelphia, but Priestley preferred the serenity and wild seclusion of Northumberland, where his three sons and other English emigrants had attempted to found a settlement for the friends of liberty. The scheme had been abandoned, but Priestley's children stayed on. Here the amateur chemist built himself a home and a laboratory, and settled down to writing and experimenting. Thomas Jefferson came to consult him in regard to the founding of the University of Virginia. Occasionally he left Northumberland to attend the meetings of the American Philosophical Society at Philadelphia before which he read several scientific papers, or to take tea with George Washington, who had invited him to come at any time without ceremony.

Toward the end of 1797 Priestley's laboratory was completed, and before the close of the century he performed his greatest chemical experiment in America. Still working with gases, he passed steam over glowing charcoal and collected a new gas, now known as carbon monoxide. The discovery of this colorless gas explained for the first time the light blue flickering flame seen over a furnace fire. To-day much of the gas used in our homes for cooking and lighting is manufactured in essentially the same way originated by Priestley in 1799.

He continued to communicate with his friends of the Lunar Society to whom he sent accounts of his scientific discoveries. They in turn did not forget him, and, as late as 1801 Watt and Boulton presented him with "furnace and other apparatus for making large quantities of air."

Priestley's long years of preaching and experimenting were now drawing to a close. Had he not been hampered by his deep-rooted belief in the phlogiston of Becher, his contributions in the field of chemistry would undoubtedly have been greater. Much that he discovered was not very clear to him, for he saw those things in the false light of the phlogiston theory. He had called an hypothesis a cheap commodity, yet Becher's hypothesis held him in its power, and clouded almost every great conclusion he had drawn. Across the sea a chemical revolution was taking place. Phlogiston as a working foundation was being annihilated. One by one its believers were forsaking it for a newer explanation born in the chemical balance. The great protagonists of science were gradually being won over to the new chemistry. Priestley alone, of the eminent chemists of the time, clung tenaciously to Becher. So thick-ribbed a believer was he in this theory that, when his health began to fail him, and he was no longer strong enough to light the fire in his laboratory, Priestley sat down in the quiet and tranquillity of his study to throw the last spear in defense of phlogiston. "As a friend of the weak," he wrote to Berthollet in France, "I have endeavored to give the doctrine of phlogiston a little assistance."

In this document, the last defense of phlogiston, Priestley honestly and courageously stated his beliefs. He was not altogether blind to the apparent weaknesses of the theory which he still championed. "The phlogistic theory," he wrote, "is not

without its difficulties. The chief of them is that we are not able to ascertain the weight of phlogiston. But neither do any of us pretend to have weighed light or the element of heat." He had followed the fight very closely. Here in America his friends were helping in the destruction of the phlogiston hypothesis. Within the pages of Dr. Mitchill's *Medical Repository* many had discussed the fire principle. James Woodhouse, Professor of Chemistry at the University of Pennsylvania, Pierre Adet, French Minister to the United States and devotee of chemistry, and John MacClean of Princeton University, besides Dr. Mitchill and Priestley, had threshed out the matter in a friendly spirit.

Priestley felt keenly the overthrow of this doctrine. It had served men of science for a century and had pointed out a way. "The refutation of a fallacious hypothesis," he declared, "especially one that is so fundamental as this, cannot but be of great importance to the future progress of science. It is like taking down a false light which misleads the mariner, and removing a great obstacle in the path of knowledge. And there is not perhaps any example of a philosophical hypothesis more generally received or maintained by persons of greater eminence than this of the rejection of phlogiston. In this country I have not heard of a single advocate of phlogiston." And yet, in spite of this, he was not a mental hermit. He honestly believed in phlogiston—he had been brought up in it; yet he was open-minded. "Though I have endeavored to keep my eyes open, I may have overlooked some circumstances which have impressed the minds of others, and their sagacity," he added, "is at least equal to mine." His was not the stupid, obstinate clinging to an old hypothesis simply because it had been handed down. He sincerely believed in its truth. "Yet," he wrote, "I shall

still be ready publicly to adopt those views of my opponents, if it appears to me they are able to support them."

Priestley was now past seventy. Mentally he was still very alert; physically his tired body was beginning to show signs of weakness. "I have lived a little beyond the usual term of human life," he told his friends. "Few persons, I believe, have enjoyed life more than I have. Tell Mr. Jefferson that I think myself happy to have lived so long under his excellent administration, and that I have a prospect of dying in it. It is, I am confident, the best on the face of the earth, and yet, I hope to rise to something more excellent still." Death did not crush him. A year after his arrival in America he had lost his son Henry, after only a few days' illness, and within a few months his wife, too, was taken from him. But he hoped soon to meet them again, for he awaited a real material return of Christ upon earth.

At eight o'clock, Monday morning, February 6, 1804, the old minister lay in bed knowing the end was very near. He called for three pamphlets on which he had lately been at work. Always a careful writer, clearly and distinctly he dictated several changes to be made before they were sent to the printer. He asked his secretary to repeat the instructions he had given him. The dying man was dissatisfied: "Sir, you have put it in your own language; I wish it to be in mine." He then repeated his instructions almost word for word, and when it was read to him again, he was contented. "That is right," he said, "I have done now." Half an hour later he was dead.

Priestley's home in Northumberland, still in perfect preservation, was dedicated by the chemists of America a few years ago as a permanent memorial. Close to this building there has been erected a fireproof museum to house much of his ap-

paratus—flasks, gun barrels, glass tubes, vials, corks, bottles, balance, crucibles, pneumatic trough—chiefly the work of his own hands. Among this collection is a large compound burning-glass similar to the one with which he prepared the gas that has placed the name of Joseph Priestley among the immortals of chemistry.

V

CAVENDISH

A MILLIONAIRE MISANTHROPE TURNS TO THE ELEMENTS

IN 1366 King Edward III of England raised John de Cavendish to the exalted office of Lord Chief Justice of the King's Bench. Sir John could trace his ancestry back to Robert de Gernon, a famous Norman who aided William the Conqueror. This same Cavendish was later murdered for revenge, because his son was accused of slaying Wat Tyler, leader of an insurrection. Two centuries later the name of Cavendish was again glorified by the noted freebooter Thomas Cavendish, the second Englishman to circumnavigate the globe.

On October 10, 1731, at Nice, a son was born to Lady Anne Cavendish, who had gone to France in search of health. This Cavendish was not destined to wield power in public life, as his parents had hoped. Rather did he devote his long life to the cultivation of science purely for its own sake. In him the pioneer spirit was to push back the frontiers of chemical knowledge.

Here was a singular character who played with chemical apparatus and weighed the earth, while more than a million pounds deposited in his name in the Bank of England remained untouched. His bankers had been warned by this scion of nobility not to come and plague him about his wealth, or he would immediately take it out of their hands.

Gripped by an almost insane interest in the secrets of nature, this man worked alone, giving not a moment's thought to his health or appearance. Those who could not understand the

curiosity of this intellectual giant laughed at the richest man in England, who never owned but one suit of clothes at a time and continued to dress in the habiliments of a previous century, and shabby ones, to boot. This man could have led the normal life of an active nobleman. His family wanted him to enter politics, but instead he lived as a recluse, and devoted his life to scientific research. While other natural philosophers wasted time and energy squabbling over the priority of this or that discovery, or arguing one theory or another, Cavendish could be found among his flasks and tubes, probing, experimenting, discovering—altogether unconcerned about the plaudits and honors of his contemporaries.

An immense fortune, inherited after he was forty, gave him that material independence so necessary to the research worker. A temperament that knew neither jealousy nor ambition gave him the freedom of mind so vital to the clear and unemotional consideration of theoretical problems. It is no wonder that he was able to accomplish so much in his long life.

A mind so free of dogma could not stand the strict religious tests applied to candidates for degrees at the universities. After spending four years at Cambridge, where he knew the poet Gray as a classmate, Cavendish left without taking a degree, and went to London.

Unlike Priestley, when the phlogiston theory began to crumble, he did not cling to it to the last, even though he did not openly accept the newer chemistry of Lavoisier, believing it at best “nearly as good” as phlogistonism. Elusive phlogiston still remained only a word, while all the natural philosophers of Europe and America went hunting for it in every school and private laboratory. When, in 1772, Priestley was being honored with a medal for his discovery of soda water, the President of the Royal Society, Sir John Pringle, remarked: “I must ear-

nestly request you to continue those liberal and valuable inquiries. You will remember that fire, the great instrument of the chemist, is but little known even to themselves, and that it remains a query whether there be not a certain fluid which is the cause of this phenomenon." Here was the biggest single problem in chemistry. If this principle of fire could only be trapped—if it could be captured between the sealed walls of a bottle to be shown to every sceptical chemist, then Becher and his followers would be vindicated. To identify it with heat or light as Scheele and Macquer had done was not sufficient. It must be ponderable and possess all the other properties of real matter.

In the sixteenth century the Swiss medicine man, Theophrastus Paracelsus, had noticed bubbles of air rising from sulphuric acid when pieces of iron were thrown into it. He had also discovered that this gas could burn, but that was the limit of his investigation. Later Jan Van Helmont, a Flemish physician, made a similar observation, but he, too, neglected to continue the study of this gas.

Then came Cavendish, to whom the pursuit of truth in nature was a thing almost ordained. He, likewise, had noticed the evolution of a gas when zinc or iron was dropped into an acid. He went cautiously to work to investigate this phenomenon. He hated errors and half truths, and while the instruments which he constructed for his experiments were crudely fashioned, they were made accurately and painstakingly. This eccentric mortal, who could make the half mythical calendar of the Hindoos yield consistently numerical results, proposed to investigate this mysterious gas which burned with a light blue flame. Perhaps here he would find the key to phlogiston. Perhaps this gas was phlogiston itself!

He took a flask and poured sulphuric acid into it. Then into

the acid he threw some bits of zinc. Through a cork which sealed the mouth of the flask, he attached a glass tube to the end of which a bladder was tied. Slowly at first, and then more rapidly, bubbles of a colorless gas began to rise from the surface of the metal to find their way into the bladder. Then, when the bladder was full, Cavendish sealed it and set it aside. He repeated this experiment, using iron instead of zinc, and again collected a bladderful of gas. Still another metal he tried—this time tin, and now a third bladder of gas was collected. Cavendish must make sure of his conclusions. He repeated these three experiments using hydrochloric acid instead of sulphuric, and three more sacs of gases were prepared.

The experimenter now brought a lighted taper to his six samples of gas. He watched each specimen of gas burn with the same pale blue flame. Strange that the same gas should be evolved in each case! What else could this inflammable air be, but that elusive phlogiston? For had not Becher taught that metals were compounds of phlogiston and some peculiar earths? Surely Cavendish had proved that the gas came, not from the acids or water in the bottles, but from the metals themselves! But he must not announce this until he had investigated further—it would not do to startle the world before he had made certain he was right.

With the crude instruments at his disposal, he passed the gases through drying tubes to free them of all moisture, and then he weighed the pure imprisoned “phlogiston.” Though extremely light he found it actually had weight. It was ponderable. He had nailed phlogiston itself! Now, at the age of thirty-five, he published an account of this work on *Factitious Airs* in the *Transactions of the Royal Society*.

Priestley, accepting these results, discussed them with the members of the Lunar Society and the “Lunatics,” as they were

called, agreed with him. Boulton especially was enthusiastic. "We have long talked of phlogiston," he declared, "without knowing what we talked about, but now that Dr. Priestley brought the matter to light we can pour that element out of one vessel into another. This Goddess of levity can be measured and weighed like other matter."

So immersed was Cavendish in the phlogiston of Becher that he did not know he had isolated, not the principle of fire, but pure, colorless, hydrogen gas.

When the daring Frenchman, Pilatre de Rozier, heard of this invisible combustible gas, he tried some queer experiments to startle the Parisians. He inhaled the gas until he filled his lungs, and then, as the gas issued from his mouth, set fire to it. Paris held its sides as it watched this Luciferous devil spitting fire. When, however, he endeavored to set fire in the same way to a mixture of this gas and common air, "the consequence was an explosion so dreadful that I imagined my teeth were all blown out," and he turned to other applications of the gas. Dr. Charles of Paris constructed the first large hydrogen-filled balloon, and in the presence of three hundred thousand spectators de Rozier bravely climbed inside the bag and started on the first aerial voyage in history.

There were many who would not accept this inflammable hydrogen as the real phlogiston. Even England's literary genius, Samuel Johnson, busied himself with chemical experiments—Boswell tells us: "a life-long interest." Now past sixty-three, he found running around London increasingly arduous. Boswell tells us that he sent Mr. Peyton to Temple Bar with definite instructions: "You will there see a chemist's shop at which you will be pleased to buy for me an ounce of oil of vitriol, not spirits of vitriol. It will cost three halfpence." He, too, was going to investigate.

Cavendish now continued to pry into the problem of what really happens when a substance burns in the air. He was true scientist enough to consider what others had already done about this problem. He set feverishly to work to read some pamphlets.

In Dean Street, Soho Square, the quietness of which Dickens so well described in his *Tale of Two Cities*, Cavendish had filled a London mansion with his library, and during his long continued researches in the field of science he had occasion to refer to many of its volumes. Dressed as a gentleman of the previous half century, this shabby, awkward, nervous philosopher would come here to draw his books. His soiled, yet frilled shirt, his cocked hat, buckled shoes, and high coat collar pulled up over his neck, made this pernickety eccentric a ludicrous figure. Advancing towards the librarian, the fair-complexioned man would talk into space while asking for his books. He would sign a formal receipt for the volumes he was borrowing—this he insisted upon—and then walk slowly home, always taking the same path. He would thrust his walking stick in the same boot and always hang his hat on the same peg. He was a creature of habit, rigidly self-imposed, and seldom did he vary his daily routine.

Here was a lively account of an electrical machine which Pieter van Musschenbroek, a Dutch physicist, had accidentally discovered in 1746 while attempting to electrify water in a bottle. This Leyden jar, as it was called, produced sparks of electricity at the operator's will. It was a curious instrument and a powerful one whose shocks were claimed to work miraculous cures. It was shown to gaping crowds throughout rural England and on the Continent. Nine hundred monks at a monastery in Paris, formed in a single line linked to one another by iron wire, gave a sudden and tremendous jump as the dis-

charge of this mighty device was sent through them. They would not take another shock for the Kingdom of France!

Cavendish was fascinated by such stories. He read also about Franklin's experiments with atmospheric electricity—how he had flown a kite in the summer of 1752 and felt the electric shock of the thunderstorm. This force must be a powerful weapon, thought Cavendish, for a year later a Russian scientist who tried the same experiment had been killed. Here was a potent instrument which the chemist might use to solve great mysteries.

He read in another pamphlet of an experiment performed about ten years after Franklin's. Giovanni Beccaria, an Italian, had passed some electric sparks through water, and had noticed a gas issuing from the water. But he missed discovering a great truth. Cavendish, the acute, saw something significant behind this ingenious experiment. He read on. The year which marked the beginning of the American Revolution witnessed an experiment by an Englishman, John Warltire. This natural philosopher who helped Priestley in the discovery of oxygen, was trying to determine whether heat had weight or not. In a closed three-pint copper flask, weighing about a pound, he mixed some common air and hydrogen, and set fire to the mixture by means of an electric spark. An explosion took place inside the flask, and, upon examination, Warltire detected a loss in weight of the gases, and incidentally the formation of some dew. Cavendish saw in this another clew to a great discovery which had just been missed by inches.

Now he came across another natural philosopher, Pierre Joseph Macquer, a scientist of the Jardin des Plantes, who described an experiment he had performed that same year. He, too, set fire to hydrogen in common air, and as the gas burned he placed a white porcelain saucer in the flame of the

inflammable gas. The flame was accompanied by no smoke—the part of the saucer touched by the flame remained particularly white, “only it was *wetted by drops of a liquid like water*, which indeed appeared to be nothing else but pure water.”

Cavendish heard from his friend Priestley, working away in his laboratory in Birmingham. On April 18, 1781, this preacher-scientist, using the spark of an electric machine, fired a mixture of common air and hydrogen in a closed thick glass vessel. He was working on a different problem at this time so that his observations were not very pertinent when he wrote, “Little is to be expected from the firing of inflammable air in comparison with the effects of gunpowder.” Cavendish’s suspicions became more and more confirmed.

The facts seemed to be as clear as daylight. He went to his bottles and his bladders, his gases and his electrical machine to probe a great secret. The way had been shown him—this fact Cavendish, like Priestley, never denied. He sought no fame in the pursuit of truth. Not that anything mattered to this misanthrope, yet he could not help peeping into nature’s secrets. He was a machine, working to unfold hidden truths—not because they were useful to mankind, but because he delighted in the hunt.

Suddenly the voice of his housekeeper was heard through the door which separated his laboratory from the rest of the house. “I found your note on the hall table this morning, Sir. You have ordered one leg of mutton for dinner.” “So I have,” cried Cavendish gruffly. He was not to be disturbed. He had more important things to think about than his stomach. “But, Sir,” ventured the maid, “some of your friends from the Royal Society are expected here for dinner.” “Well, what of it?” stammered Cavendish. “But,” she pleaded, “one leg of mutton will not be enough for five.” “Well, then, get two legs,” came

the final reply. She dared not risk another question. She knew how strange and frugal was her master.

Cavendish was busy repeating the experiments of Warltire, Macquer, and Priestley. He performed them with greater skill and care, and with a clearer understanding of what was before him. He had cut down the underbrush and headed straight for his goal. Day after day, week after week, this "wisest of all rich men and richest of all wise men," hit nearer and nearer to his target. And as he worked, the solution of his problem grew clearer. He did not jump to hasty conclusions. Instead of common air, which his predecessors had used, Cavendish employed the newly discovered oxygen. He broke many a flask as he sparked this explosive mixture of oxygen and hydrogen. A great number of measurements and weighings had to be repeated. He had the patience of an unconquerable spirit. Had he not read of Boerhaave, the Dutchman whose fame as physician had spread so far that a Chinese mandarin seeking medical aid had sent a letter addressed: "Boerhaave, celebrated physician, Europe"? Boerhaave, in an endeavor to discover a chemical fact, had heated mercury in open vessels day and night for fifteen successive years. Cavendish could be just as persevering.

Here was an error in his figures which he had not noticed before. He must dry his gases to remove every trace of water. And there was another matter he had failed to take into account in measuring the volumes of his gases. He proceeded to change the volumes of his gases to conform to standard conditions. Where the ordinary experimenter detected one flaw, this recluse saw two and sometimes many more. As his calculations filled page after page, his results began to verify one another. Now, after more than ten years of labor, Cavendish was almost ready to make public his proofs. Had he not, like his contemporaries,

delayed the publication of these results, he would not have started a controversy which lasted half a century.

Before March, 1783, he made known his experiments to Priestley. Then his friend Blagden was informed of his work, and the following June, Blagden notified Lavoisier. The year 1783 passed and Cavendish had not yet published the result of his work. He never displayed that keen desire to rush into print which so generally ensues an important discovery.⁷ He was interested in experimentation—not publicity through publication. Not until the following January did he read his memoir on *Experiments on Air* before the Royal Society of England.

And this is what he told them: "Water consists of dephlogisticated air united with phlogiston." Translated into the language of modern chemistry, Cavendish informed his hearers that water was really a compound of two gases, hydrogen and oxygen, in the proportion of two volumes of hydrogen to one volume of oxygen. That clear, life-sustaining, limpid liquid was not the simple elementary substance all the savants of the world thought it to be. Not at all. The crowning wonder of chemistry had formed it out of two invisible gases.

What a startling announcement! Water a compound of two tasteless vapors! Where were his proofs? Cavendish told them quietly and without emotion. He had introduced into a glass cylinder, arranged so that its contents could be sparked without unsealing the vessel, four hundred and twenty-three measures of hydrogen gas and one thousand parts of common air. When they were sparked "all the hydrogen and about one-fifth of the common air lost their elasticity and condensed into a dew which lined the glass." Hydrogen and oxygen had combined to form pure potable water.

But how could he be sure that this dew was really water?

They were certain to ask this question. He had to prove it for them. He collected very large volumes of the gases—500,000 grain measures of hydrogen and 1,250,000 grain measures of common air, and burned the mixture slowly. “The burnt air was made to pass through a glass cylinder, eight feet long and three-quarters of an inch in diameter. The two airs were conveyed slowly into this cylinder by separate copper pipes, passing through a brass plate which stopped up the end of the cylinder.” He thus condensed “upwards of one hundred and thirty-five grains of water which had no taste or smell and left no sensible sediment when evaporated to dryness, neither did it yield any pungent smell during the evaporation. In short, it seemed pure water.” Positive enough experiments—tests that were infallible, and yet Cavendish said “it seemed.” He suspected his listeners would not be convinced. Water a compound of two gases—incredible!

Cavendish went further. “If it is only the oxygen of the common air which combines with the hydrogen,” he argued, “there should be left behind in the cylinder four-fifths of the atmosphere, as a colorless gas in which mice die and wood will not burn.” He tested the remnant of the air left in the cylinders and found that to be the case. The nitrogen gas was colorless and mephitic. He weighed all the gases and all the apparatus before and after sparking, and found that nothing had been added or lost. Only oxygen and twice its volume of hydrogen had disappeared, and in their place he always found water of the same weight.

To convince the sceptics, Cavendish varied his experiments once more. Now he used only pure gases, not common air but pure oxygen obtained, as Priestley had shown him, by heating the red powder of mercury. He took a glass globe (still preserved in the University of Manchester), holding 8800 grain

measures, furnished with a brass stop-cock, and an apparatus for firing air by electricity. The globe was well exhausted by an air-pump, and then filled with a mixture of pure hydrogen and oxygen. Then the gases were fired by electricity as before. The same liquid water resulted and the same gases disappeared. Again he weighed the gases and their product as well as the glass globe, before and after combining them. Again the same remarkable result—two volumes of hydrogen always united with one volume of oxygen to form a weight of water equal to the weights of the gases. He had proved it conclusively.

A few years later Deiman and Paets van Troostwijk passed electric sparks from a frictional machine through water and decomposed it into hydrogen and oxygen. Fourcroy, in France, left burning 37,500 cubic inches of hydrogen and oxygen continuously for a week, and got nothing else but water. There could no longer be any question about the nature of water.

In the history of science is now recorded the story of a great controversy. It stands beside the great discussion of 1845 between the friends of John Adams, an Englishman, and Urbain Le Verrier, a young Frenchman, as to the real discoverer of Neptune, the outermost planet of our solar system, and the equally vehement controversy between the friends of Dr. Jackson and William Morton as to the true pioneer in the use of ether as an anesthetic.

Three men were claimants to the discovery of the composition of water. Two of them claimed the discovery for themselves, the third for Cavendish. Priestley, who too might have sought credit for this discovery, or who might at least have helped settle the discussion, remained for a time on the sidelines, watching the great verbal battle.

Two months after Cavendish read his paper to the Royal Society, Le Duc communicated the contents of this same dis-

covery to James Watt, the inventor, who had likewise been interested in experiments on the nature of water. In consequence of this communication, Watt transmitted a report to the same Society, claiming its discovery as early as April of the preceding year. Lavoisier laid claim to its discovery on the basis of an oral report submitted in conjunction with Laplace to the French Academy in June, 1783. In this report he announced the composition of water without acknowledging any indebtedness to other scientists, even though he had by that time been informed by Blagden of the work of Cavendish.

Cavendish was not interested in such squabbles. When, in August, 1785, the shy, unsocial chemist visited Birmingham, where Watt was living, he met the Scotch engineer and spent some time with him discussing their researches. Watt, too, was not looking for notoriety, and while they said not a word about the priority of the discovery of water, both felt that Lavoisier might have been gracious enough to have acknowledged that his work on water was based on their previous work. Ten years later came Lavoisier's tragic end, and by 1819 the last of the figures directly concerned in the water controversy had died.

Another twenty years passed, and little was mentioned of this matter. Then Dominique Arago, celebrated astronomer and Secretary of the French Academy, came to England to gather material for a eulogy of James Watt. He made what seemed to him a thorough examination of the water controversy, and came to the conclusion that James Watt was the first to discover the composition of water, and that Cavendish had later learned of it from a letter written by Watt to Priestley. And while the principals of these wranglings lay in their graves, their friends started a turmoil which did not subside for ten years. The friends of Watt accused Cavendish of deliberate plagiarism. To vindicate Cavendish, the President of the British Associa-

tion for the Advancement of Science published a lithographed facsimile of Cavendish's original notebook, and to-day the world gives credit for the discovery of the nature of water to him who sought this honor least.

The more Cavendish frowned upon fame the more fame wooed him. At twenty-nine he had been elected a fellow of the Royal Society (F. R. S.) following in the footsteps of his father who had been honored with that society's Copley Medal for inventing the maximum and minimum thermometers. Every Thursday this awkward, gruff-speaking philosopher attended its meetings to keep in close touch with the progress of science. He seldom missed a meeting, and while he kept a good deal to himself, his ear was always cocked for new developments in science. He was appointed member of a committee to consider the best means of protecting a powder magazine against lightning, and the following year was placed in charge of a meteorological bureau which was to make and record daily observations of temperature, pressure, moisture and wind velocity around the building of the Royal Society.

Cavendish was even persuaded now and then to attend a *soirée* of the Society held at the home of its president, Sir Joseph Banks. He would be seen standing on the landing outside, wanting courage to open the door and face the people assembled, until the sound of stair-mounting footsteps forced him to go in. On one such occasion this tall, thin, timid man was seen in the center of a group of distinguished people. His eyes downcast, he was visibly nervous and uncomfortable. Suddenly he flew panic-stricken from the group and rushed out of the building. He had been talking with an acquaintance when John Ingenhousz, Dutch physician to Maria Theresa, appeared. Cavendish recognized this scientist by his queer habit of wearing a coat boasting buttons made of the recently discovered



HENRY CAVENDISH

metal platinum. With Ingenhousz was a gentleman who had heard of Cavendish and wanted to be introduced to the illustrious philosopher. Cavendish was annoyed almost to frenzy, but managed to control his temper. But when the dignified Austrian visitor began to laud him as a famous and most distinguished man of science, then Cavendish, with a queer cry like that of a frightened animal, bolted from the room.

Cavendish had turned the family residence, a beautiful villa at Clapham, into a workshop and laboratory. The upper rooms became his astronomical laboratory, for he was interested in every phase of natural phenomena. On the spacious lawn he had built a large wooden stage which led to a very high tree. When he was sure not to be seen, he would climb this tree to make observations of the atmosphere. Often, in the dusk of the evening, Cavendish would walk down Nightingale Lane from Clapham Common to Wandsworth Common. He took this walk alone, rambling along in the middle of the road, performing queer antics with his walking stick, and uttering strange, subdued noises. Once when, to his utter horror, he was observed climbing over a stile by two ladies, he forsook that road forever, and thenceforth took his solitary walks long after sundown.

There is only one likeness of Cavendish in existence—a water-color sketch which hangs in the British Museum. It was impossible to make him sit for his portrait. The painter Alexander had to sketch this one piece-meal while Cavendish was completely unaware that he was being taken.

Cavendish was a confirmed woman-hater. He never married—he could not even look at a woman. Returning home one day, he happened to meet a female servant with broom and pail on the stairway. So annoyed was he at seeing her that he immediately ordered a back staircase to be built. He had al-

ready dismissed a number of maids who had crossed his path in the house. On another occasion, he was sitting one evening with a group of natural philosophers at dinner, when there was a sudden rush to the windows overlooking the street. Cavendish, the scientist, was curious. He, too, walked over to gaze, as he expected, at some spectacular heavenly phenomenon. Pshaw! he grunted in disgust. It was only a pretty girl flirting from across the street!

Although a misanthrope, Cavendish was, strangely enough, charitable. His unworldliness made him an easy mark for unscrupulous beggars and borrowers, and he was even addicted to handing out blank checks. He naïvely believed every charity monger who accosted him. One of his librarians became ill, and Cavendish was approached for help—a hundred pounds would have more than sufficed. But Cavendish, too impatient to listen to the verbose details of the plea, asked if ten thousand pounds would do. It did!

As an experimenter Cavendish was superb—to him science was measurement. In 1781 he had collected, on sixty successive days, hundreds of samples of air, gathering them in all sorts of ingenious ways, and from as many different places as he could possibly reach. He subjected these samples to innumerable experiments, weighings, and calculations. He was repeating the work of Priestley and others, which was to lead him to the conclusion that the atmosphere had an almost uniform composition in spite of its complex nature. He was the first accurate analyst of the air. He had found air to contain twenty per cent of oxygen by firing it with pure hydrogen gas in a glass tube. During these experiments, a small quantity of an acid had found its way into the water in the eudiometer. He was not the first to detect this impurity; Priestley, Watt, and Lavoisier had all observed it, but they were at a loss to explain

its formation. Cavendish, however, was not satisfied to leave this observation without a reasonable explanation. Again he showed his powers as an original researcher. By a series of carefully planned and skillfully executed experiments he tracked this minute quantity of acid to its source. He found it to be the result of a chemical reaction between the nitrogen and oxygen of the air, during the passage of the electric spark through the eudiometer. This he demonstrated privately to some friends. Nitrogen and oxygen had united to form oxides of nitrogen which Priestley had already prepared. This discovery was the basis of the first process used in the commercial fixation of nitrogen utilized in the manufacture of fertilizers and high explosives.

Cavendish determined to change all the nitrogen of the air into nitrous acid by repeated sparking of the air in an enclosed vessel. During these experiments he left records in his notebooks of the crowning achievement which stamped him as one of the outstanding scientific experimenters among the early chemists. It had taken a hundred years to discover a gas which Cavendish during these experiments had isolated from the air. What every investigator before him, and for a century after him, had either missed entirely or ignored, Cavendish noticed and recorded.

A hundred years of chemical progress passed. Lord Rayleigh and Sir William Ramsay, two of his compatriots, while searching for a suspected element in the air, turned over the pages of Cavendish's memoirs, at Dewar's suggestion, and read this statement: "I made an experiment to determine whether the whole or a given portion of the nitrogen of the atmosphere could be reduced to nitrous acid. . . . Having condensed as much as I could of the nitrogen I absorbed the oxygen, after which *only a small bubble of air remained unabsorbed*, which

certainly was not more than $1/120$ of the bulk of nitrogen, so that if there is any part of the nitrogen of our atmosphere which differs from the rest, and cannot be reduced to nitrous acid, we may safely conclude that it is not more than $1/120$ part of the whole."

Here was a clue to their search. They repeated the experiments of Cavendish and isolated a small volume of gas from the nitrogen of the air. They subjected it to every test for an unknown, and identified a new element. Small wonder that this colorless, odorless, insoluble gas would not form nitrous acid, as Cavendish had remarked. This idle gas, *argon*, was found to be incapable of combining with even the most active element. It was present in the atmosphere to the extent of one part in 107 by volume. Henry Cavendish had recorded one part in 120—remarkable accuracy in the light of a century of experimental advance.

From this clew came also the later discovery of three other inert elements of the air. From liquid argon, the same scientists separated new "neon," hidden "krypton," and "xenon" (the stranger) present to the extent of one part in eighty thousand, twenty million, and one hundred and seventy million parts of air respectively. With modern apparatus at his disposal it is not difficult to believe that Cavendish might have been the discoverer of these *noble gases* one hundred years before they were given to the world.

Cavendish's writings were rendered somewhat obscure by the verbiage of phlogiston. He knew no other chemical language. When the flood of the new chemistry began to rise in France, when the chemical revolution which followed the French Revolution began to question and destroy the beliefs in which he had been reared, Cavendish changed to a new field of scientific research. And while the world of science was set agog by the

new developments in chemistry, Cavendish was busy measuring the force with which two large leaden balls attracted two small leaden balls. He was finding the weight of the earth. He would rather do this than be embroiled in the heat and fury of foolish discussions over new theories.

Cavendish left London on very rare occasions. He visited Sir Humphrey Davy a number of times to watch him experiment on the alkalis in which he used some pieces of platinum which Cavendish had given him. During these meetings his conversation could not have proved very agreeable. The utterance of unnecessary words he regarded as criminal. Once, while staying in a hotel at Calais with his younger brother Frederick, whom he saw seldom, they happened to pass a room through the open door of which they could see a body laid out for burial. Henry was much attached to his brother, yet not a single word passed between them until the following morning, when, on the road to Paris, the following lengthy conversation broke their silence:

Frederick to Henry: "Did you see the corpse?"

Henry to his brother: "I did."

This man never wasted a single word, spoken or written, on the beauties of natural scenery, even though he had spent his whole life engrossed in the study of nature. In the diary of his travels we may come, with surprise, upon the following: "At —— I observed ——". What?—a piece of sculpture or a beautiful sunset? No! only the readings of a barometer or thermometer. He inherited from his father an intense interest in mathematical measurements. On those rare occasions when he travelled in his carriage, he attached to the wheels an antique wooden instrument, called a "way-wiser," to show him how far he was travelling. His biographer has summed up his life thus: "Such was he in life, a wonderful piece of intellectual

clockwork, and as he lived by rule he died by it, predicting his death as if it had been the eclipse of a great luminary."

One evening Cavendish returned as usual from the Royal Society and went quietly to his study. He was ill, but this non-religious man told no one. Soon growing worse, he rang the bell and summoned his servant. "Mind what I say," he told him, "I am going to die. When I am dead, *but not till then*, go to my brother, Frederick, and tell him of the event. Go." An hour passed. Cavendish was growing weaker. Again he rang for his valet. "Repeat to me what I have ordered you to do," he demanded. This was done. "Give me the lavender water. Go."

Another half-hour passed, and the servant, returning, found his master a corpse. Thus passed England's great chemical luminary, leaving part of his fortune to science, and his fame to be commemorated in the Cavendish Laboratory for Experimental Research at Cambridge, where to-day other oracles are travelling the path he helped illuminate.

VI

LAVOISIER

THE GUILLOTINE ROBS THE CHEMICAL BALANCE

DURING the frenzy of the French Revolution, when the King and Queen were guillotined for conspiracy against the liberty of the nation, and a dozen men sitting in the Palace of the Tuilleries were sending thousands to their death, a scientist was quietly working in a chemical laboratory in Paris.

This scientist was a marked man. He had given much of his energy and wealth to the service of France, but hatreds were bitter in those days and he had many enemies. Yet, while the streets of the city were seething with excitement, and his foes were planning to destroy him, he stood over his associate, Seguin, and slowly dictated notes to his young wife beside him.

Seguin was seated in a chair in the laboratory. He was hermetically enclosed in a varnished silk bag, rendered perfectly airtight except for a slit over his mouth left open for breathing. The edges of this hole were carefully cemented around his mouth with a mixture of pitch and turpentine. Everything emitted by the body of Seguin was to be retained in the silken bag except what escaped from his lungs during respiration. This respired air was passed into various flasks and bottles, finally to be subjected to an accurate and complete analysis. Whatever escaped from Seguin's body in the form of perspiration or other waste material was to remain sealed in the silken covering.

Lavoisier was investigating the processes of respiration and perspiration of the human body. Weighings of Seguin, the silk

bag, the inhaled air, and the respired air, and determinations of the gain in weight of the bag and loss in weight of his associate, were made on the most accurate balances in all France. Lavoisier trusted his scales implicitly. But these experiments were never to be completed by him. The door of his laboratory was pushed open with sudden violence. A pompous leader, wearing the liberty cap of the revolutionists, entered the room, followed by the soldiers of the Revolutionary Tribunal and an uncontrollable mob.

Marat, member of the National Assembly and self-styled Friend of the People, had attacked the scientist in bitter, dangerous terms: "I denounce to you this master of charlatans, Monsieur Lavoisier, son of a rent collector, apprentice chemist, tax collector, steward of ammunition and saltpetre, administrator of discount funds, secretary to the King, member of the Academy of Sciences. Just think of it, this little gentleman enjoyed an income of forty thousand livres and has no other claim to public gratitude than to have put Paris in prison by intercepting the circulation of air through it by means of a wall which cost us poor people thirty-three million francs, and to have transferred the gunpowder from the Arsenal to the Bastille the night of the 12th or 13th of July, a devil's intrigue to get himself elected administrator of the Department of Paris. Would to heaven he had been hanged from the lamp post!"

Lavoisier had offended this man years before. He had exposed Marat as a very poor chemist when the latter had tried to gain election to the Academy of Sciences. The future revolutionary had struck back and denounced Lavoisier as "the putative father of all the discoveries that are noised about, who having no ideas of his own snatches at those of others, but having no ability to appreciate them, rapidly abandons them and changes his theories as he does his shoes." The learned

societies of France had been suppressed for harboring disloyal citizens. Even among his scientific collaborators Lavoisier had enemies. Fourcroy and de Morveau, scientists and members of the Assembly and Convention, loathed the old government, and Lavoisier, aristocrat and appointee of the King, became an object of their hate.

Paris was ready to listen to such inflammatory words. The conflict of the privileged classes and the third estate had culminated in the Reign of Terror, during which a Committee of Public Safety sent traitors, conspirators, and suspects to a quick doom. The deluge had come. Lavoisier had been, until very recently, a member of the Fermes Générales, a sort of Department of Internal Revenue made up of aristocrats. It was essentially a financial company whose members paid the government a nominal sum for the privilege of collecting taxes which they themselves kept. They had been guilty of outrageous abuses and were finally ordered disbanded.

As the document for his arrest was read, Lavoisier serenely and bravely made ready to obey the order. Saying goodbye to his wife, he entrusted his unfinished manuscript to Seguin and left his laboratory for the last time. In May, 1794, he was called by the Committee of Finance before the Revolutionary Tribunal. He was tried and falsely convicted on the grounds that he had plotted against the government by watering the soldiers' tobacco, and had appropriated revenue that belonged to the State. Others before him had been condemned for less. In spite of the petitions of his friends in the Bureau of Consultation, who reminded the judge of the greatness of this man of science, in spite of Lavoisier's years of unselfish devotion to his country, Coffinhal, president of the Tribunal, would not relent. "The Republic has no use for savants." The sentence was death, and no appeal could be taken. Carried in a cart

to the Place de la Révolution, he and twenty-seven others were to be decapitated. The third to be executed was his father-in-law, and then the head of Lavoisier fell into the insatiable basket of the guillotine. "It took but a moment to cut off that head, though a hundred years perhaps will be required to produce another like it." This was the verdict of the great mathematician Lagrange, then living in Paris. Truer words were seldom uttered. Thus died France's great chemical revolutionist. His burial place has never been found for the body was lost in that mad upheaval.

Just a month before, Priestley had fled from the religious bigotry of England. His great work had already been done. But Lavoisier was cut off in the midst of productive investigations, and who can say what might have come from this genius? "Until it is realized that the gravest crime of the French Revolution was not the execution of the King, but of Lavoisier, there is no right measure of values; for Lavoisier was one of the three or four greatest men France has produced." This is the judgment of posterity.

The eighteenth century witnessed the efforts of other chemists besides Priestley and Cavendish. Hundreds were working with the flask, the crucible, and the balance. And while the great oracles of chemistry were discovering new truths or unmasking old errors, these lesser lights kept plodding away, building up a storehouse of chemical facts which soon cried out for order. Every bit of chemical information dug out of the fruitful mines of Europe's laboratories was put to the test of phlogiston. Phlogiston was the all-explaining touchstone. If this universal principle seemed unable to fit a new discovery into the structure of chemistry, then those ingenious creatures of the crucible could twist it into a form which would fit.

Scheele's chlorine, that yellowish greenish gas which both

kills and purifies, and which the Swedish apothecary had torn out of muriatic acid, was explained by the phlogistonists as being oxy-muriatic acid. Water was a compound of the phlogisticated air of Cavendish and the dephlogisticated air of Priestley. Rutherford's nitrogen was mephitic air devoid of phlogiston. The language of chemistry, too, was stagnant; it had not been revised or rejuvenated since the ancient days of alchemy, and its literature was filled with such barbarous expressions as phagadenic water, pomphlix, oil of tartar per deliquim, butter of antimony, calcothar and materia perlata of Kerkringius. Yet in spite of this confusion of terms and explanations, the facts kept piling up, waiting only for someone to dispel the mist that enshrouded and enveloped chemistry. It is truly remarkable that, working in such a wilderness, those early researchers were able to extricate so much of permanent value.

Lavoisier's appearance at this juncture was timely. Chemistry was in dire need of such a figure. Here was a man of influence whose voice was not lost. His were the words of power and position, not only in the councils of natural philosophers, where he had no peer, but also in the assemblies of politics, where he played a leading part. Lavoisier was heard, and science profited by the tactics of the publicity agent. Liebig said of him, "He discovered no new body, no new property, no natural phenomenon previously unknown. His immortal glory consists in this—he infused into the body of science a new spirit."

Lavoisier's mind was clear. He had been trained in mathematics and physics. Few possessed better foundations for the pursuit of the science of chemistry. His well-to-do parents had sent this imaginative boy to the Collège Mazarin, where at first he intended to study law. But he soon turned to science.

He was greatly influenced by Guillaume Rouelle who held the position of "Demonstrator" at the Jardin des Plantes. For more than a century and a half it was the custom here for the Professor of Chemistry to lecture on the theory and principle of science. He performed no experiments and never soiled his fingers with chemicals. His realm was theory.

Bourdelain was Professor at the time. Concluding his discourse he would wind up with "Such, gentlemen, are the principles and the theory of this operation. The Demonstrator will now prove them to you by his experiments." And as Bourdelain stepped out of the room, Rouelle appeared, greeted with loud applause. Fashionable audiences came to listen to him. Lavoisier sat spellbound as Rouelle, instead of proving all the theory of the Professor, would, with his skillful experiments, destroy it. The young student never forgot how Rouelle one day became excited and waxed eloquent. Removing his wig which he hung on a retort, and throwing off his waistcoat, he suddenly rushed out of the lecture hall, in search of some chemical apparatus, still absentmindedly continuing to lecture while out of sight and hearing of his audience.

On one of his scientific excursions Lavoisier met Linnæus, the great Swedish naturalist and botanist, who, too, captivated his interest. He definitely decided to devote his life to science.

Young Lavoisier's activities soon became so varied that he had scarcely time to eat. He started to write a drama, *La Nouvelle Héloïse*, which was never completed. One full day each week he lived in his laboratory—never leaving it for a moment. Besides this he worked at his furnace every day from six to nine in the morning and from seven to ten at night. He would not allow himself the luxury of leisurely eating. To save time, he put himself on a bread and milk diet. One of his friends felt the need of warning Antoine. "I beseech you," he

wrote, "to arrange your studies on the basis that one additional year on earth is of more value to you than a hundred years in the memory of man." Accompanying this letter was a package containing a bowl of thin, milky porridge. Lavoisier, however, did not adopt this suggestion. Before he was twenty-five, the French Academy of Sciences had already heard from him on such diverse subjects as the divining rod, hypnotism, and the construction of chairs for invalids. He soon gained recognition, and was elected a member of this body. Young as he was, he directed an active discussion about a wholesome drinking water supply for the city of Paris, and his practical mind led him to advocate fire hydrants as a protection against great conflagrations in crowded communities.

In the year following his admission to the Academy, Lavoisier became associated with the *Fermes Générales*, and made the acquaintance of Jacques Paulze de Chastenolles. Monsieur Paulze, member of the *Fermes Générales*, was an aristocrat at whose home gathered many men prominent in the social and political life of France—Turgot, Comptroller General of France; Laplace, greatest of French astronomers; Franklin, the American; Condorcet, mathematician and humanitarian; and Pierre Du Pont de Nemours, who later, marked for destruction, emigrated to America with his sons, to found the great industrial institution that still bears his name. To Paulze's home came also Antoine Laurent Lavoisier, young, good-looking, keen-minded, a good conversationalist, and eager to mix with the intellectual élite of France. Lavoisier soon became interested, not so much in the distinguished guests, but in a petite, blue-eyed brunette, the daughter of Paulze. Lovable little Marie Anne Pierretti became very fond of the tall, gray-eyed, simple-mannered scientist. Her father noticed this and encouraged the lovers. Antoine was eligible! Soon the busy man

found time to walk with Marie Anne, and he would talk to this fourteen-year-old girl about love, and his career in the field of science. She understood. She was going to study English, Latin and even science so that she could help him in his work. Besides, she had a talent for drawing and they planned to have Marie do the drawings and plates for his scientific memoirs. The courtship was a short one, and when they were married that year they were given a beautiful home at 17 Boulevard de la Madeleine with a salon over which Mme. Lavoisier was to preside. It was a happy marriage, and Marie never showed that violence of temper which she displayed years later when she remarried. During a stormy domestic quarrel she is said to have ordered her second husband, Count Rumford, out of the house with the warning never to return.

Lavoisier's first research in chemistry was a simple analysis of gypsum. Then this son of a wealthy Parisian merchant directed all his skill toward an attack upon the old notion that water could be converted into earth and rocks. Ever since Thales of Miletus, worshiping the Nile, had attributed the origin of all things to water, science had believed that water became stone and earth by evaporation. For twenty centuries this had been taught. Men had taken flasks of water and heated them over fires until all the water had boiled out. Inside the flasks they had found dull, earthy substances which must have come from the water. Van Helmont had planted a small willow tree weighing five pounds in a pot of two hundred pounds of earth that had been thoroughly dried and weighed. He had nourished the plant for fifteen years with nothing but water, and the tree had increased in weight to one hundred and sixty-nine pounds. The soil having in the meantime lost but two ounces, he had "proved" that water had been converted into

one hundred and sixty-four pounds of solid material in the tree! Lavoisier saw the obvious fallacy of this demonstration.

"As the usefulness and accuracy of chemistry," he held, "depend entirely upon the determination of the weights of the ingredients and products, too much precision cannot be employed in this part of the subject, and for this purpose we must be provided with good instruments." Borrowing the most sensitive balance of the French Mint, he weighed a round-bottomed flask which he had cleaned until it glistened in the sunlight. Into this flask he poured a measured volume of drinking water, which he distilled into another carefully weighed flask. Just as he expected, a gray, earthy material clung to the bottom of the empty flask. He weighed the flask and its earthy impurity and subtracted from this the weight of the flask. He thus obtained the weight of the earth. He compared this weight of earth with the loss in weight sustained by the drinking water during distillation. The weights were identical! This earth must have come from the drinking water! But he had still to answer this question: Was this solid impurity which clung to the glass *dissolved* in the drinking water, or had the water *changed* into an earthy material?

He took a pelican, an alchemical flask shaped so that a boiling liquid would drop back again into the same flask. Into this pelican he poured a definite weight of pure sparkling rain-water and boiled the liquid over a low even fire. For one hundred consecutive days he distilled this rain-water, never allowing the fire beneath the flask to go out. When he finally stopped the distillation, he noticed a few specks of solid material floating in the water. They had not been there before. He weighed the pelican and its contents. There was no loss in weight. The distilled water, too, had remained constant in weight during the long boiling. Then he placed the pelican on

a balance and found it had lost weight equal to that of the solid material in the flask. These seventeen grains of mud, he concluded, must have come from the glass of the pelican. There was no other explanation. The water itself had remained unchanged. Water could never be transmuted into earth. With the aid of his balance Lavoisier had destroyed another mistaken heritage of antiquity.

Lavoisier was a careful worker with an idea at the back of his head which grew clearer as he read or repeated the experiments of his predecessors and contemporaries. Slowly he began to weed out the faulty explanations and weak theories that had crept into chemistry. Phlogiston did not fit into his scheme of chemistry. While the rest of Europe clung to it tenaciously he could see through it. To him it was a myth, an idle mischievous theory with neither foundation nor substance. There must be a simpler and more logical explanation of burning than Becher's phlogiston. With the coolness and dexterity of a skilled surgeon, he began to dissect the old idea. The creature was rotten to the core.

With scientific intuition he rejected this theory before he had thought of a substitute, but he was going to find an alternative. This practical Lavoisier who, at twenty-two, received a gold medal from the Academy of Sciences for working out the best method of lighting the streets of Paris; this same Lavoisier who, before submitting his essay, had worked for months on this problem, shutting himself up in a dark room for six weeks to render his eyes more sensitive to different lights; he was going to find the true explanation of burning! Phlogiston would not do.

He quickly dropped phlogiston and jumped to "caloric," or heat. Half a century before, the French Academy had offered a prize for an essay on the nature of heat. All the three win-



LAVOISIER
Arrested by the Revolutionists

ners favored a materialistic theory. It was not strange, therefore, that Lavoisier accepted the explanation that heat was a subtle fluid which penetrated the pores of all known substances. He frankly admitted, however, that he had no very clear conception of the real nature of this caloric. "Since there are no vessels which are capable of retaining it," he wrote, "we can only come at the knowledge of its properties by effects which are fleeting and difficultly ascertainable."

In avoiding the pitfall of one monstrosity, Lavoisier fell into the snare of caloric, the imbecile heir of phlogiston. It is difficult to explain this widespread acceptance of caloric. There were some, however, who recognized the evil kinship of phlogiston and caloric, among them Benjamin Thompson, the first great chemist of American birth. This adventurer had left Massachusetts to fight on the side of the English during our War for Independence. In Bavaria, as Count Rumford, he had a model law passed to put a stop to mendicancy. Problems of science also interested him. He made a study of foods and promptly tested his pet theories while feeding the troops of the Elector of Bavaria. While in charge of the military foundry in Munich, he bored through a cannon surrounded by a wooden box containing two gallons of water, which in two hours began to boil. The astonishment of the bystanders was indescribable. Water boiling without fire! He had transformed the mechanical force of a horse-driven boring machine into the energy of heat. To Count Rumford heat was a form of energy, the energy of particles of matter in motion as Newton and Lomonossov, a Russian, had held—not a ponderable fluid. He knew that caloric would soon perish. To a friend he wrote, "I am persuaded that I shall live a sufficiently long time to have the satisfaction of seeing caloric interred with phlogiston in the same tomb."

But caloric was not quite so vicious a theory. Here was the great difference between the myth of phlogiston and the fiction of caloric. Lavoisier did not depend upon caloric to explain the facts of chemical changes. His chemistry was not *based* upon vaporous caloric, while Becher's phlogiston was the actual foundation of the structure of chemistry. Lavoisier wanted to crush phlogiston. To appease those chemists who demanded a substitute, he gave them the comparatively harmless prescription of caloric. Believe in it or not, caloric would do no harm either way. It served as a vicarious palliative to save chemistry from the lethal dose of phlogiston.

But even Lavoisier was not satisfied with caloric as an explanation of burning. The phenomenon of burning still puzzled him. He was determined to solve it scientifically. Neither the fetish of phlogiston nor the belief in caloric was going to decide it. "We must trust in nothing but facts. These are presented to us by nature and cannot deceive. We ought in every instance to submit our reasoning to the test of experiment. It is in those things which we neither see nor feel that it is especially necessary to guard against the extravagances of imagination which forever incline to step beyond the bounds of truth." Rich enough to secure the best in apparatus and chemicals, he spared neither wealth nor effort. As he worked, he kept building chemical structures in his mind, rejecting one after another as his furnace brought cogent objections.

Lavoisier worked tirelessly. He was bound to conquer the mystery of burning. After years of experimentation he reached a conclusion. He went to his desk and penned to the French Academy a memoir to be kept hidden and unread until he had completed further experiments. In this sealed note he wrote: "A week ago I discovered that sulphur on being heated gained weight. It is the same with phosphorus. This increase in weight

comes from an immense quantity of air. I am persuaded that the increase in weight of metal calces is due to the same cause. Since this discovery seemed to be one of the most interesting which had been made since the time of Becher, I have felt it my duty to place this communication in the hands of the secretary of the Academy, to remain a secret until I can publish my experiments." Always shrewd, Lavoisier made sure that no one would snatch away from him the credit for the discovery of a great truth. By entrusting his secret memoir to the Academy he established his priority to the discovery of the nature of burning.

This was November 1, 1772. Priestley had not yet concentrated the heat of the sun's rays upon his red mercury; oxygen was still undiscovered. For three years more Lavoisier labored to unravel further the meaning of fire.

In October 1774, Priestley visited his fellow scientist in his laboratory in Paris, and gave him an account of his experiments on the preparation of oxygen. Macquer was present and helped to correct Priestley's imperfect French. Lavoisier, armed with this information, immediately performed his classic Twelve Day Experiment.

"I took a matrass (a glass retort)," he wrote, "of about thirty-six cubic inches capacity, and having bent the neck so as to allow its being placed in the furnace in such a manner that the extremity of its neck might be inserted under a bell glass placed in a trough of quicksilver, I introduced four ounces of pure mercury into the matrass. I lighted a fire in the furnace which I kept up almost continually during twelve days. Nothing remarkable took place during the first day. On the second day, small red particles began to appear on the surface of the mercury: these during the four or five following days gradually increased in size and number, after which they ceased

to increase in either respect. At the end of twelve days, I extinguished the fire."

He examined the air which was left in the matrass. It amounted to about five-sixths of its former bulk, and was no longer fit for respiration or combustion. Animals were suffocated in it in a few seconds, and it immediately extinguished a lighted taper. This remaining gas was, of course, nitrogen. He then took the forty-five grains of red power which were formed, and heated them over a furnace. From these he collected about forty-one and a half grains of pure mercury and about eight cubic inches of a gas "greatly more capable of supporting both respiration and combustion than atmospherical air." He had prepared a pure gas which he later named oxygen or "acid former" thinking it to be a constituent of *all* acids.

Lavoisier came forward with an explanation of burning which completely rejected the old notion of phlogiston. That air was necessary for combustion and breathing was known. Leonardo da Vinci during the fifteenth century believed "fire destroyed without intermission the air which supports it and would produce a vacuum if other air did not come to supply it." Paracelsus back in 1535 wrote that "man dies like a fire when deprived of air." Robert Boyle, too, was "prone to suspect that there may be dispersed through the rest of the atmosphere some odd substance on whose account the air is so necessary to the subsistence of flame." But what function did this air play? Jean Rey had, years before, curiously explained that the increase in weight of a burning object came from the air "which has been condensed and rendered adhesive by the heat, which air mixes with the calces not otherwise than water makes sand heavy by moistening and adhering to the smallest of its grains." But no sensible scientist could accept such an explanation.

Lavoisier described this experiment to the French Academy

a few months later, mentioning not a word of the work of Priestley. In a letter to his friend, Dr. Henry, written on the last day of that memorable year, the English minister felt that Lavoisier "ought to have acknowledged that my giving him an account of the air I had got from *mercurus calcinatus* led him to try what air it yielded, which he did presently after I left." It is difficult to explain this omission, for Lavoisier later acknowledged his indebtedness to Priestley for his work on the composition of nitric acid.

Lavoisier was the first to interpret the facts clearly. Burning, he said, was the union of the burning substance with oxygen, the name he gave to the dephlogisticated air discovered by Priestley. The product formed during burning weighed more than the original substance, by a weight equal to the weight of the air which combined with the burning body. Simple enough. No mysterious phlogiston, not even caloric—and the testimony of the most sensitive balances in Europe to support his reasoning.

Everything was accounted for by his three delicate balances. His most sensitive one, for weighing about a fifth of an ounce, was affected by the five-hundredth part of a grain. To Lavoisier, the balance was indispensable. It allowed nothing to escape his attention. "One may take it for granted that in every reaction there is an equal quantity of matter before and after the operation. Thus, since wort of grapes gives carbonic gas and alcohol, I can say wort of grapes equals carbonic acid and alcohol." All chemical changes obeyed the law of the indestructibility of matter. Likewise, in this chemical change of burning, nothing was gained or lost. Even the vaporous air was weighed and made to give consistent results. There was no intangible ghost mixed up in his explanation. Here was a new, unorthodox

idea—an exposition that ushered in a revolution in chemical thought.

The world did not accept Lavoisier's explanation at once. But he kept on working. Emperor Francis I had heated three thousand dollars' worth of pure diamonds for twenty-four hours. The diamonds disappeared. They had volatilized, or changed to vapor, he thought. Lavoisier saw the error. He heated a diamond away from air and it lost no weight. But when he subjected it, inside a jar of oxygen, to the heat of the sun's rays, it disappeared and changed into carbon dioxide. Carbon had burned or oxidized into carbon dioxide gas. In the meantime, Cavendish had proved the composition of water. Lavoisier brilliantly repeated the work of this Englishman and introduced an ingenious experiment to verify the composition of water from the standpoint of his new theory of combustion. These experiments were conclusive. French scientists began to rally around him—Fourcroy, De Morveau, Berthollet, and others.

Outside France, opposition was still strong, especially in England where William Ford Stevenson F.R.S., in an exposé of the "deception" of Lavoisier, declared: "This arch-magician so far imposed upon our credulity as to persuade us that water, the most powerful natural antiphlogistic we possess is a compound of two gases, one of which surpasses all other substances in its inflammability." Cavendish, discoverer of the composition of water, never accepted the new explanation. As late as 1803 Priestley wrote from Pennsylvania, "I should have greater pride in acknowledging myself convinced if I saw reasons to be, than in victory, and shall surrender my arms with pleasure. I trust that your political revolution will be more stable than this chemical one."

Yet Lavoisier's contribution triumphed. In Edinburgh, Dr.

Black accepted his explanation and passed it on to his students. Italy and Holland fell into line at about the same time. From Sweden, Bergman wrote to Lavoisier offering him his support. The Berlin Academy of Sciences, urged by Martin Klaproth, ratified Lavoisier's views in 1792. American scientists rallied to him almost to a man. Even Russia endorsed the new system, for it boasted of a forerunner of Lavoisier in the person of Michael Vasilievic Lomonossov, vodka-loving poet and scientist who a generation back had "conducted experiments in air-tight vessels to ascertain whether the weight of a metal increased on account of the heat," and "showed that without the admission of external air the weight of the metal remained the same."

Then Lavoisier delivered a master stroke. He realized the importance of language to a science. In 1789, while the Bastille was being stormed, he published his *Traité Élémentaire de Chimie*, which helped destroy another citadel of error. This book was written in the new language of chemistry. For the first time a text book spoke the language of the people. Lavoisier took chemistry away from the mystics and the obscurantists, and gave its knowledge to every man who would learn. Too long had this science been burdened and obscured by cryptic words and pompous phrases. Uncouth and barbarous terms were to be banished forever. Secret "terra foliata tartari of Muller" became potash. The new nomenclature coupled with a scientific explanation of the process of combustion gave chemistry a new birth.

The new terminology had not sprung up overnight. As early as 1782, four men began to meet regularly in "the little Arsenal," the chemical laboratory of Lavoisier on Rue Neuves-Bons Enfants, in Paris. There were Guyton de Morveau, a lawyer who had come to Paris to suggest the simplified nomenclature to Lavoisier; Berthollet, personal instructor of

chemistry to Napoleon; and Antoine François Fourcroy, dramatist and relentless orator of the Reign of Terror, all seated around Lavoisier. A herculean task was before them. What a jumble of names, what a mess of alchemical débris had to be sorted out and organized! Lavoisier spoke calmly to his collaborators: "We must clean house thoroughly, for they have made use of an enigmatical language peculiar to themselves, which in general presents one meaning for the adepts and another meaning for the vulgar, and at the same time contains nothing that is rationally intelligible either for the one or for the other." "But," ventured the mild Berthollet, "there might be objections to a radical change." Some had raised the cry of ancestor worship. "The establishment of a new nomenclature in any science ought to be considered as high treason against our ancestors, as it is nothing else than an attempt to render their writings unintelligible, to annihilate their discoveries and to claim the whole as their own property." This accusation had come later from Dr. Thomas Thomson, who reproached the French scientists for their presumption in daring to change the language spoken and written by their masters. Others resented the effort to interfere with the "genius of the language." But Lavoisier answered, "Those who reproach us on this ground have forgotten that Bergman and Macquer urged us to make the reformation." De Morveau upheld his leader, "In a letter which the learned Professor of Upsala, M. Bergman, wrote a short time before he died he bids us spare no improper names; those who are learned will always be learned, and those who are ignorant will learn sooner."

The four kept working, and in May, 1787, a treatise on the new nomenclature of chemistry was proposed before the French Academy. In Ireland that odd chemist, Kirwan, lying on his belly on a hot summer's day before a blazing fire, and

eating ham and milk, received the new language of chemistry with disdain. "So Lavoisier has substituted the word 'oxide' for the calx of a metal," he sneered. "I tell you it is preposterous. In pronouncing this word it cannot be distinguished from the 'hide of an ox'. How impossible! Why not use Oxat?" He refused to agree to the new changes "merely to gratify the indolence of beginners." But Lavoisier's views prevailed. Professor Thomas Hope, at the University of Edinburgh, soon after his arrival from Paris, was the first teacher to adopt the new nomenclature in his public lectures. Dr. Lyman Spalding, at Hanover, New Hampshire, published some chemical tracts in the new system, using the name "septon" for nitrogen and "septic acid" for nitric acid, on the principle that nitrogen was the basis of putrefaction.

During his lifetime, Lavoisier's name was known throughout France for his varied activities. He rivaled Franklin in his versatility. In 1778 he was named by King Louis XVI member of a committee to investigate the strange claims of a physician who had come to Paris from Vienna. This Dr. Friedrich Mesmer created a great deal of excitement by practicing what he called "animal magnetism." The King and Queen suspected a plot. Lavoisier and Benjamin Franklin, who was also on the committee, watched the new miracle man, at a séance, making passes over a patient and finally putting him into a trance. Mesmer then suggested to the sleeper a cure for his ailment, and, by some occult magnetic influence which passed from the doctor to the sick one, the patient was cured. Both Lavoisier and the American Ambassador vigorously denied that animal magnetism had anything to do with the trance whose reality, nevertheless, they admitted. And as the actuality of his cures remained unsettled Mesmer continued to

attract disciples, among the most ardent of whom was young Lafayette.

At thirty-two, as comptroller of munitions, Lavoisier abolished the right of the State to search for saltpetre in the cellars of private houses, and by improving methods of manufacture, increased France's supply of this chemical. Later he was appointed to investigate new developments in the manufacture of ammunition. On October 27, 1788, accompanied by his wife, he went to the town of Essonnes to report on some experiments. When within a few hundred feet of the factory, they heard a terrific explosion. Rushing to the ruins Lavoisier found several mutilated bodies. He had missed death by moments. The experiments, nevertheless, were continued.

Although condemned as a "damned aristocrat," Lavoisier was by no means blind to the poverty and suffering of the lower classes. In spite of his being a staunch royalist, he urged reforms simply on humanitarian principles. He believed that in these reforms lay France's political salvation. Investigating conditions among the French farmers, he reported to the comptroller-general that "the unfortunate farmer groaned in his thatched cottage for lack of both representation and defenders." He realized they were being neglected, and tried to improve their economic status. At Fréchine, Lavoisier established a model farm, and taught improved methods of soil cultivation and other aspects of scientific farming. During a famine in 1788, he advanced his own money to buy barley for the towns of Blois and Romorantin. To avoid a recurrence of such suffering, he proposed a system of government life insurance for the poor. Blois remembered this act of kindness, and in December of that year sent him as its representative to the States General. Lavoisier, the humanitarian, also made a tour of inspection of the various prisons in Paris, and ex-

pressed his utter disgust at France's method of treating her criminals. The dungeons were foul, filthy, and damp—he recommended an immediate fumigation of all these pest-holes with hydrogen chloride gas, and the introduction of sanitation.

Yet to-day the undying fame of Lavoisier rests not upon these social palliatives, but upon the secure foundation of his explanation of burning, and the simplified chemical nomenclature we have inherited from him. Armed with these new weapons, men were equipped to storm the bulwarks of chemical obstruction.

VII

DALTON

A QUAKER BUILDS THE SMALLEST OF WORLDS

IN MAY, 1834, there came to London from the city of Manchester, a tall, gaunt, awkward man of sixty-six years. He was dressed in Quaker costume; knee breeches, gray stockings, buckled shoes, white neckcloth, gold-topped walking stick. His friends had raised a subscription of two thousand pounds for a portrait statue of this world-famous natural philosopher. He had come to sit to Sir Francis Chantrey, the court sculptor, who was to mold his head in clay, and then model a life-sized statue to be placed in the hall of the Manchester Royal Institution. The clay model of the head of the venerable seer was soon completed. As Chantrey sat chatting with him, he carefully scrutinized his head, which looked so much like the head of Newton. He noticed that the ears of the philosopher were not both alike, while the model showed the two ears to be the same. In a moment the sculptor leaped to his feet, cut off the left ear of the bust, and proceeded to fashion another one. The old schoolmaster-scientist was amused. How absurdly careful was this Chantrey!

Honors came pouring in on this scientist. The French Academy of Sciences elected him a corresponding member. He was made a Fellow of the Royal Society of England, and President of the Literary and Philosophical Society of Manchester. And now his friends wished to present him to the King, who, years before, had given a gold medal to be awarded to him for his great scientific contributions. Henry Brougham, the Lord

Chancellor, offered to present him to His Majesty. But this could not be arranged without breaking the rules of the Court. John Dalton was a Quaker who still respected the tenets of his religion, even though forty years before, loving certain favorite airs, he had dared ask permission of the Society of Friends to use music under certain limitations. A Quaker could not wear court dress because this included the carrying of a sword. A way was soon found out of the difficulty. The University of Oxford had recently conferred upon him an honorary degree. He could be properly introduced to the King in the scarlet robes of a Doctor of Laws. The old philosopher agreed. The part was carefully rehearsed. "But what of these robes?" someone pointed out. "They are scarlet, and no Quaker would wear such a colored garment." "You call it scarlet," replied Dalton who was color-blind. "To me its color is that of nature—the color of green leaves."

The stage was all set for the momentous event. Dalton approached King William IV and kissed his hands. They stood chatting for a while. "Who the devil is that fellow whom the King keeps talking to so long?" someone asked. He had never seen John Dalton and had probably never heard of him, for Dalton led a very uneventful, contemplative life. From this studious existence, however, came one of the greatest contributions to chemistry—a contribution upon which much of the later chemistry rested.

Dalton, like Priestley, was the son of a poor English weaver. When only twelve years old he had already requested permission from the authorities of his native village of Eaglesfield to open a school. He had by this time studied mensuration, surveying, and navigation, and his scientific knowledge convinced the authorities of his competence. They remembered how, at the age of ten, he had astonished the farmers of his village by

solving a problem they had discussed for hours in a hay field. He had proved to them that sixty square yards and sixty yards square were not the same. He was always solving mathematical problems for which he won many prizes. Like most boys, he would have preferred to do other things than teach, but his poor Quaker parents had five other children, and John had to help.

At first he opened his school in an old barn, and later held his classes in the meeting house of the Friends. Some of his pupils were boys and girls much older than he. He did not mind teaching them so long as he could find time after school to make weather observations. He had become deeply engrossed in the study of the atmosphere. What a hobby that was! He would rather mark down all sorts of weather observations in one of his innumerable notebooks, than hunt or fish or go swimming. He worked for hours at a time constructing crude thermometers, barometers, and even hygrometers. Between his duties as a schoolmaster and his work as farmer on his father's small patch of land, the boy found time to play with the atmosphere and dream of it.

As this lad grew older, he studied Latin, Greek, mathematics, and more natural philosophy. But his hobby of meteorology fascinated him most of all. When he was fifteen he left Eaglesfield for the village of Kendal to teach in the school which his brother Jonathan conducted. As he passed through Cockermouth, he saw an umbrella. He had never seen one before, except in prints of fine ladies and gentlemen. He bought the umbrella, feeling, as he said years later, that he was now to become a gentleman. At the Kendal school his authority was soon questioned. One of the older boys challenged the young schoolmaster to a fight in the graveyard. Dalton knew he was

no match for this bully. He locked the ruffian in his room, and his classmates outside broke his windows in revenge.

In 1793, at the recommendation of his friend John Gough, a distinguished, blind, natural philosopher of Kendal, Dalton was invited to become tutor in mathematics and natural philosophy at Manchester College at an annual salary of eighty pounds. But he needed more time and freedom for his all-absorbing pursuit of aerology. At the close of the century, he resigned from the college to become a private tutor, earning his livelihood at two shillings a lesson. He might have gone on a lecture tour, but he knew he was a failure as a public lecturer. He had been convinced of this when at Kendal he had given twelve lectures on natural philosophy to the general public, charging one guinea for the entire course. These discourses included such fascinating subjects as astronomy and optics. But his deep, gruff, indistinct voice, his slow association of thoughts, his dry humor and unattractive appearance, could not draw a large audience, although he had announced that "subscribers to the whole course would have the liberty of requesting further information, also of proposing doubts or objections." Even the lure of a public forum in science had not made his lectures popular.

Dalton could devote more time now to his study of the atmosphere. He made scores of weather observations every day. Occasionally he was called away to other cities to tutor. His life became filled with such a passion for collecting data on the air that when he went to Edinburgh, London, Glasgow, or Birmingham, he never failed to spend most of his time making observations and recording results. When conditions permitted him to take a brief vacation, he travelled to the Lake District, where he added to his almost numberless records. He tramped through northern England, explored valleys, forded streams,

climbed mountains, went sailing over the lakes, not for health or pleasure, but with a greater incentive—he was studying the atmosphere. He never forgot to carry his scientific apparatus. For forty-six consecutive years he kept records of the daily weather and atmospheric conditions, and there were few entries missing in this colossal record of more than two hundred thousand observations. Goethe, at sixty-eight, hearing of Dalton's passion for weather observations, took to this new science of meteorology, and made numerous cloud calendars.

Dalton never married. He said he had no time for such a luxury. Yet he enjoyed the society of beautiful and talented women. In Lancaster there was a family of Friends he never failed to visit when in the neighborhood. In writing to his brother Jonathan, who likewise remained a bachelor, John was not ashamed to admit his infatuation. "Next to Hannah," he declared, "her sister Ann takes it in my eyes before all others. She is a perfect model of personal beauty." He is even said to have composed verse to this lady. When he visited London in 1809 to attend a meeting of the Royal Society, he reported to his brother, "I see the belles of New Bond Street every day. I am more taken up with their faces than their dress. Some of the ladies seem to have their dresses so tight around them as a drum, others throw them round like a blanket. I do not know how it happens, but I fancy pretty women look well anyhow." A generous observation from a pious Quaker.

His only relaxation, besides his scientific excursions, was bowling. Every Thursday afternoon he went outside the town to the "Dog and Partridge" to indulge in a merry game of bowls. A few pence for each game were paid for the use of the green, and Dalton meticulously noted his gains and losses in his book. He could really never stop entering figures in notebooks.



JOHN DALTON

As Dalton's observations on the atmosphere filled notebook after notebook, he began to wonder about a problem which no one had as yet made clear. He knew that the atmosphere was composed of four gases—oxygen, nitrogen, carbon dioxide, and water vapor. Priestley, Rutherford, Cavendish, and Lavoisier had proved that point. But how were these gases held together? Were they chemically united or were they merely mixed together, just as one mixes sand and clay? There were two theories. Berthollet believed the air to be an unstable chemical compound, while others considered it a physical mixture of gases.

Dalton's own observations led him to accept the idea that air was a mechanical mixture of gases. Yet the composition of the atmosphere was constant. His records proved that without question. He had analyzed the atmosphere taken from hundreds of different places in England—from the tops of mountains, over lakes, in valleys, in sparsely settled regions and in crowded cities. Yet the composition was the same. Gay-Lussac in France had ascended in a balloon filled with hydrogen to an altitude of 21,375 feet over Paris, and had collected samples of air at this height. And this air differed only very slightly from the air taken in the streets of the city. Why did not the heavier carbon dioxide gas settle to the bottom of the sea of air, covered in turn by the lighter oxygen, nitrogen, and water vapor? Had he not tried to mix oil and water and had not the lighter oil collected at the surface of the heavier water? Perhaps the currents of air and the constantly moving winds mixed the gases of the atmosphere and kept their composition uniform.

Dalton could not understand it. Had he gone to the laboratory, where the masters of chemistry had sought out the answers to other baffling questions? He had tried, but his flasks had not

helped. Dalton knew himself—he was not a careful experimenter. This problem had to be solved in the workshop of his brain.

Dalton had read Lavoisier's *Traité Élémentaire de Chimie*. The French chemist had suggested that the particles of a gas were separated from each other by an atmosphere of heat or caloric. "We may form an idea of this," he had written, "by supposing a vessel filled with small spherical leaden bullets among which a quantity of fine sand is poured. The balls are to the sand as the particles of bodies are with respect to the caloric; with this difference only, that the balls are supposed to touch each other, whereas the particles of bodies are not in contact, being retained at a small distance from each other by the caloric."

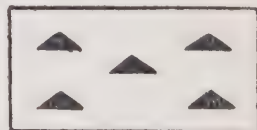
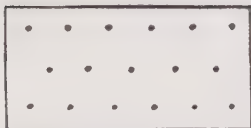
Perhaps diagrams would help. Dalton drew pictures—he was enough of the pedagogue to know how much a simple sketch had helped his students understand a hazy point.



This drawing represented the water vapor in the air.

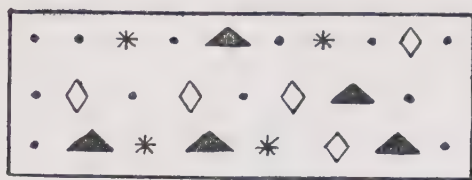


This would stand for the oxygen of the atmosphere.



These dots were the nitrogen, and small black triangles designated the carbon dioxide of the atmosphere. Now he mixed

these signs together, and drew a picture to represent how these gases were found present in the atmosphere, thus:



His pictorial mind began to see the particles of the different gases diffusing through each other, and thoroughly mixing, thus keeping the composition of the atmosphere uniform.

While he was interpreting this physical phenomenon of the diffusion of gases, a little word began to loom larger and clearer in his mind. He had come across that word in his readings. Kanada, the Hindu "atom eater," had centuries ago conceived matter to be discontinuous and made up of small eternal particles in perpetual motion. Leucippus, a famous scholar and teacher of Greece, had also speculated on the nature of matter twenty-four centuries before Dalton, and had concluded that everything consisted of tiny particles of various kinds, separated by space through which they travelled. Then Democritus, the "laughing philosopher" who in 500 B.C. declared, "We know nothing, not even if there is anything to know," developed his teacher's idea, and taught that matter was composed of empty space and an infinite number of invisible atoms, *i.e.* small particles. "Why is water a liquid?" asked Democritus. "Because its atoms are smooth and round and can glide over each other." Not so with iron, however, whose atoms are very rough and hard. He constructed an entire system of atomism. Color was due to the figures of the atoms, sourness was produced by angular atoms, the body of man was composed of large sluggish atoms, the mind of small mobile atoms while the

soul consisted of fine, smooth, round particles like those of fire. Even sight and hearing were explained in terms of atoms. Lucretius in his poem *De Rerum Natura* taught the same idea to the Romans.

The Manchester schoolmaster had also read of Newton's ideas regarding matter. "It seems probable to me," wrote Newton, "that God in the beginning formed matter in solid, massy, hard, impenetrable, movable particles. . . . so very hard as never to wear or break to pieces; no ordinary power being able to divide what God himself made One, in the first creation." A beautiful idea, thought Dalton, but was this really true? He pondered over it constantly. Suddenly, after deep thought, the whole atomic theory was revealed to him. He did not wait for experimental verification. Like Galileo, he did not feel that experimental proof was always absolutely essential. Like Faraday, he possessed, to an extreme degree, a sense of physical reality. Dalton, cat on his knee, began to draw pictures of his atoms. Each atom was represented by a sphere, and since the atoms of the different elements were unlike, he varied the appearances of these tiny globes, as follows:

	Hydrogen,		Gold,		Carbon,
	Oxygen,		Silver,		Phosphorus,
	Nitrogen,		Mercury,		Sulphur.

Dalton, like the ancient philosophers, could not actually see the particles which he pictured. Yet his atoms were only remotely akin to the atoms of antiquity. To Dalton, atoms were definite, concrete particles of matter, even though the most delicate instrument could not render them visible to the human eye.

A hundred years after Dalton formulated his Atomic Theory, the ultramicroscope was invented by Zsigmondy and Siedentopf. This instrument revealed particles as small as one-fourth of a millionth of an inch. Yet the atom was still hidden, even to this most sensitive eye. For even the largest atom is still a hundred times smaller than the tiniest particle that the ultramicroscope can reveal. The tiniest corpuscle that the Dutch lens grinder Leeuwenhoek beheld in a drop of saliva under his crude microscope was thousands of times larger than the biggest of Dalton's atoms. In every single drop of sea water there are fifty billion atoms of gold. One would have to distill two thousand tons of such water to get one single gram of gold.

And yet Dalton spoke and worked with atoms as if they were tangible. These atoms, he claimed, were indivisible—in the most violent chemical change, the atoms remained intact. Chemical change he pictured as a union of one or more atoms of one element with atoms of other elements. Thus, when mercury was heated in the air, one atom of mercury united with one atom of oxygen to form a compound particle of oxide of mercury. Billions of these particles finally appeared to the eye as a heap of red powder of mercury. He had some spheres constructed by a Mr. Ewart which were unfortunately lost to posterity. These little spheres, one inch in diameter, he used for thirty years in teaching the Atomic Theory. He brought one ball representing an atom of mercury, in contact with another ball representing an atom of oxygen, and showed the formation of a particle of mercury oxide, thus:



+



→



1 atom of silvery,
liquid *mercury*

1 atom of colorless,
gaseous *oxygen*

1 compound particle
of red powder of
mercury oxide

Dalton asked himself another question. "Are all atoms alike in size and weight?" Here he made a distinct contribution which again stamped his theory as different from those of the ancients. Democritus had declared the atoms to be infinite in number and infinitely various in form. Dalton postulated that the atoms of the *same* element were all alike, but the atoms of *different* elements differed in both shape and weight. The weights of the atoms of each element, however, were always fixed, and never varied. Here was a bold statement. He had neither seen nor weighed an atom. Yet Dalton's Theory stood the test of more than a century of investigation, and to-day scientific evidence bears testimony to the truth of his conceptions.

In the meantime, a controversy was raging between two distinguished French chemists. Berthollet, the mild-mannered, believed that while chemical compounds showed *almost* constant composition, yet the proportions in which the elements had chemically combined were not *absolutely* rigid. Water, for example, had been proved to be a compound of oxygen and hydrogen. Berthollet insisted that, within moderate limits, the composition of this compound might vary. Usually 11.1% of hydrogen unite with 88.9% of oxygen to form water, but 11% of hydrogen might unite with 89% of oxygen, at another time, to form the same water. Strange, we might say, that so eminent a chemist as Berthollet could have championed such an absurdity. But we must remember it is still the eighteenth century, and chemistry is still in its swaddling clothes. Even at the close of the nineteenth century Ostwald, a Nobel Prize winner in chemistry, held similar views and supported Franz Wald, a Bohemian chemist and natural philosopher, who maintained that the composition of chemical compounds varied, depending upon their manner of production. Berthollet was scientist enough to experiment before making positive assertions. He made hundreds of

analyses. His conclusions, as well as those of other experimenters, seemed to add force to his claims.

The contending scientist, Joseph Louis Proust, was at that time teaching chemistry in Spain. He had made numerous experiments to determine the proportions in which various compounds were formed, and had arrived at the conclusion that Berthollet was entirely mistaken. Proust repeated the experiments of his countryman. He used the purest of chemicals and the most accurate apparatus. He took every precaution to avoid error, and found mistakes in Berthollet's determinations. Besides, Berthollet had used substances like glass, alloys, and mixtures of various liquids, all of which were not true compounds. For eight years Proust tried to persuade the scientific world, and especially the followers of Berthollet, that when elements combined to form chemical compounds, the elements united in definite proportions by weight—a theory advanced as early as the fourteenth century by Jildaki, an alchemist of Cairo.

Never did this controversy become anything more than a courteous and brilliant, truth-seeking discussion. When Berthollet, discoverer of the use of chlorine as a bleaching agent, a discovery which he would not patent but gave to the world free, when this man Berthollet saw the error of his conclusions, he graciously withdrew his arguments and accepted the conclusions of Proust. And what a marvelous order had Proust found in nature! "The stones and soil beneath our feet, and the ponderable mountains, are not mere confused masses of matter; they are pervaded through their innermost constitution by the harmony of numbers."⁸ Kepler, Galileo and Newton regarded nature as mathematical. Here was added testimony. The composition of every true compound never varies. This Law of

Definite Composition remains a fundamental principle of the science of chemistry.

This law which, for the first time, made chemistry a mathematical science, was discovered while Dalton sat sketching figures of the atoms. Dalton's little spherical atoms could very neatly confirm this law. For, if the weight of the atom of every single element is constant, and this he had postulated in his theory, then the composition of all compounds must be definite, since all chemical union meant the combination of these minute unchangeable atoms. Here is carbon monoxide, composed of one atom of carbon and one atom of oxygen: . And here is nitrous oxide made up of one atom of nitrogen and one atom of oxygen: . And  represented water, believed to contain one atom of hydrogen and one atom of oxygen. The composition of every one of these compounds must be constant, for if the eye could see beyond its limited range, it would witness single elementary atoms join hands, atom for atom, in definite combinations. How perfect, as Dalton showed, was the phenomenon of chemical union!

The ancients had speculated about the nature of matter and had written of atoms. But their atoms were not the building stones of the Manchester schoolmaster. Dalton's little figures were realities too small to be seen. He has left in his writings and charts evidences that they were, to him, concrete particles. He was not trammelled with mathematical acumen, experimental dexterity, or the wisdom of scholarly institutions. He discarded the accepted notions of scientists and contemplated nature as unbiased as a child. He would never have arrived at his immortal conception had he depended upon the results of his laboratory experiments—they were far too inaccurate. The discovery of his great generalization was based upon the imagin-

ative boldness of a mature thinker, and the simplicity of a boy playing with a hobby.

Dalton had theorized that the atoms of the different elements had different weights. If he could only find out what these weights really were! He could not think of determining the weights of the individual atoms. They were so small and light that science was to wait a century and more before those actual weights could be determined. Decades had to pass before sufficient facts could be collected and more delicate instruments perfected, to solve this problem. But Dalton realized that chemists had to know at least the *relative* weights of the atoms, lest the progress of the science be impeded. Relative atomic weights—these he could determine.

In addition to Cavendish and Lavoisier a host of other workers had accumulated a mass of mathematical results. Wenzel had studied the effects of an acid like vinegar on a base like ammonia water. Later, Jeremias Richter found that they, like other acids and bases, combined in constant proportions and in 1794 he published his *Foundations of Stoichiometry or Art of Measuring the Chemical Elements*. It was from this hazy book that G. E. Fischer collected the data which enabled him to arrange a clear, simple table. This table was the key to Dalton's problem.

He must start with the lightest substance known—hydrogen gas. Its atomic weight he took as standard and called it one. Hence, the relative atomic weights of all the other elements must be greater than one. He knew that hydrogen and oxygen united in the ratio of one to seven by weight. Dalton believed that one atom of hydrogen united with one atom of oxygen to form water. Therefore, the relative weight of the atom of oxygen was seven. In this way he prepared the first table of relative atomic weights—a table of fourteen elements, which, though

inaccurate, remains as a monument to this schoolmaster's foresight. The *Table of the Atomic Weights of the Elements*—relative atomic weights, to be sure—is to-day the cornerstone of chemical calculations.

While working on the relative weights of the atoms, Dalton noticed a curious mathematical simplicity. Carbon united with oxygen in the ratio of 3 to 4 to form carbon monoxide, that poisonous gas which is used as a fuel in the gas-range. Carbon also united with oxygen to form gaseous carbon dioxide in the ratio of 3 to 8. Why not 3 to 6, or 3 to 7? Why that number 8 which was a perfect multiple of 4? If that were the only example, Dalton would not have bothered his head. But he found a more striking instance among the oxides of nitrogen, which Cavendish and Davy had investigated. Here the same amount of nitrogen united with one, two and four parts of oxygen to form three distinct compounds. Why these numbers which again were multiples of each other? He had studied two other gases, ethylene and methane, and found that methane contained exactly twice as much hydrogen as ethylene. Why this mathematical simplicity?

Again Dalton made models with his atoms, and found the answer.

Carbon monoxide (CO) was , while carbon dioxide (CO_2) was . Nitrous oxide (N_2O) was , and  was nitric oxide (NO), while nitrogen peroxide (NO_2) could be represented as .

He had discovered another fundamental law in chemistry! Berzelius later stated this law as follows: *In a series of compounds made up of the same elements, a simple ratio exists*

between the weights of one and the fixed weight of the other element.

He wrote to Dalton to tell him that "this Law of Multiple Proportions was a mystery without the atomic hypothesis." Again Dalton's little spheres had clarified a basic truth.

On October 21, 1803, Dalton made before the Manchester Literary and Philosophical Society, of which he was secretary, his first public announcement of the relative weights of atoms. It excited the attention of natural philosophers at once. He was invited by the Royal Institution of London to lecture to a large and distinguished audience.

Dalton's atoms had started a heated discussion. His papers were translated into German. This infused a new spirit in him, and he continued to expand and clarify his theory. Then, in the spring of 1807, he made a lecture tour to Scotland to expound his theory of the atoms. Among his audience at Glasgow was Thomas Thomson, who was at work on a new textbook of chemistry. This Scotch chemist was impressed with Dalton's new conception of chemical union, and followed him to Manchester. As a result of a brief meeting, a few minutes' conversation and a short written memorandum, Thomson incorporated the Atomic Theory of Dalton in his textbook. The following year Dalton himself expounded his hypothesis in his own *New System of Chemical Philosophy*.

Before long the Atomic Theory, shuttlecock of metaphysicians for two thousand years, was finally brought to rest as an accepted and working hypothesis, eventually to be completely and experimentally proven. But not without a struggle. Those little circles of the Quaker schoolmaster were an abomination to many who would accept only what they could actually see and touch in the laboratory. They would have none of this fantastic dream.

Dr. William J. Mayo, the celebrated American surgeon, recalls that "my father was a student of Dalton and when my brother and I were small boys he told us much about this tall, gaunt, awkward scholar, and how little it was realized in his 'day that the atomic theory was more than the vagary of a scientist." It might be good enough for schoolboys who had to be amused in studying chemistry, or for natural philosophers who were never inside the chemist's sanctuary where the delicate balance and the glowing crucible told the whole truth. It was true that famous philosophers like Spinoza, Leibnitz, and Descartes had propounded similar ideas. But who listened to speculative philosophy? Lactantius, fifteen hundred years ago, had laughed at the idea of atoms. "Who has seen, felt, or even heard of these atoms?" he jeered. And now once more they sneered at the idea of atoms. Dalton was suffering from hallucinations, declared some. Instead of snakes he had visioned little spherical balls of atoms. How absurd! Was science again to be fettered by such scholasticism? What was this but confounded pictorial jugglery? Could any serious-minded chemist accept a theory just as baseless as the four elements of Aristotle that had chained men's minds for twenty centuries?

But here was a chemist, a natural scientist working in a chemical laboratory, who was bold enough to apply the idea of real atoms to chemical reactions. True, Thomson and William Hyde Wollaston, who confirmed the Law of Multiple Proportions experimentally, were ready to accept it. But Davy, England's most celebrated chemist, was bitterly hostile. He had been present at that meeting of the Royal Society when Dalton had first lectured about his atoms and had left the hall sceptical. But Dalton, an inveterate smoker, consoled himself. He could not see in young Davy any signs of a great natural philosopher, for, as he expressed himself, "Davy does not smoke."

Thomson had tried to convince Davy of the value of the theory. But Davy was adamant in his opposition, and caricatured Dalton's theory so skilfully that many were astonished "how any man of sense or science would be taken up with such a tissue of absurdities." Charles W. Eliot, the late President of Harvard University, who began his career in the field of education as a teacher of chemistry, cautioned his students as late as 1868 that "the existence of atoms is itself an hypothesis and not a probable one. All dogmatic assertion upon it is to be regarded with distrust." Berthollet, too, was so sceptical of the atomic theory that as late as 1890 he still wrote the formula for water as if it were hydrogen peroxide—to him atoms were but fabrications of the mind. Wilhelm Ostwald, who did not hesitate to champion the unorthodox theories of many young chemical dreamers, wanted as recently as twenty years ago to do away completely with the atomic theory.

Some accepted the atomic theory with reservations. Fifty years after it was formulated, one eminent English scientist declared it "at best but a graceful, ingenious, and *in its place*, useful hypothesis." But the barriers against its acceptance were finally broken down. Even Davy was eventually converted to the abominable little atoms, and in 1818, when the Government was making ready to send Sir John Ross on a scientific exploration to the Polar regions, Davy wrote to Dalton, "It has occurred to me that if you find your engagements and your health such as to enable you to undertake the enterprise, no one will be so well qualified as yourself." Dalton appreciated this compliment, but had to refuse.

At about this time William Higgins, member of the Royal Dublin Society and F.R.S., wrote a pamphlet *Observations and Experiments on the Atomic Theory and Electrical Phenomena* in which he claimed that the atomic theory had been applied

by him long before Dalton, in various abstruse researches, and that "its application by Mr. Dalton in a general and popular way gained it the name of Dalton's theory." Besides, he declared himself to be "the first who attempted to ascertain the relative weights of the ultimate particles of matter."

Here was another epic challenge in the chronicle of chemistry. Yet there was no element of attack in these statements—Higgins made no charge of plagiarism. He never even hinted at any evidence of piracy. For more than a decade he had modestly watched Dalton struggling to make the world accept his atoms, refusing to inject himself into the controversy until success had been assured for the Englishman.

Higgins was no trouble-maker. He was an eccentric Irishman of keen intellect—in fact, the first in Great Britain to see the fallacy of phlogiston. As early as 1789 when both he and Dalton were only twenty-three he had published *A Comparative View of the Phlogistic and Antiphlogistic Doctrine*. Herein he came to the defence of Lavoisier's new system of chemistry thereby daring estrangement from his irascible uncle Bryan Higgins who conducted the Greek Street School in Soho where Priestley often came for chemicals. The germ of the modern atomic theory appeared in this pamphlet. While he did not actually use the terminology of the atomic theory its method of reasoning was undoubtedly there. "Water," he wrote, "is composed of molecules formed by the union of a single particle of oxygen to a single ultimate particle of hydrogen."

Davy and Wollaston appreciated his pioneer work especially in his glimpsing of the Law of Multiple Proportions which he saw exemplified in the oxides of sulphur and of nitrogen even as Dalton years later discovered it in the oxides of carbon and nitrogen. Others, too, realized his greatness. Even Sir John Herschel in his *Familiar Lectures on Scientific Subjects* had

Hermione ask: "Do tell me something about these atoms. It seems to have something to do with the atomic theory of Dalton." "Higgins, if you please," came Herschel's answer from the lips of Hermogenes.

Yet such is the not too uncommon fate of history that Higgins died in obscurity while Dalton rose to the heights of fame. In 1822 he visited Paris and received a great ovation. The most illustrious scientists of France paid homage to him. He met Laplace, seventy-three years old, who discussed with him his development of the nebular hypothesis of cosmogony. Venerable Berthollet walked arm in arm with him for the last time, for before many more weeks had passed, France's grand old man of science was dead. Cuvier, founder of the science of comparative anatomy, delighted him with his sparkling conversation. At the Arsenal, made famous by the work of Lavoisier, Dalton met Gay-Lussac, who told him of his balloon ascents. Thénard, who four years earlier had startled the scientific world with his discovery of hydrogen peroxide, amused the English schoolmaster with experiments on this strange liquid, the second compound of hydrogen and oxygen. Dalton never forgot this cordial reception by France's scientists.

Dalton's own country did not show the same reverence to this seer of Manchester. Though past sixty, he was still compelled to teach arithmetic to private students⁹ in a small room of the Manchester Literary and Philosophical Society at 36 George Street. When, in 1833, his friends tried to get a pension for him from the Government, they were told by the Lord Chancellor that while he was "anxious to obtain some provision for him, it would be attended with great difficulty." Dalton's intimate friend, Dr. William Henry, made a last plea. "It would surely be unworthy of a great nation," he wrote, "to be governed in awarding and encouraging genius by the narrow

principle of a strict barter of advantages. With respect to great poets and great historians, no such parsimony has ever been exercised. They have been rewarded, and justly for the contributions they have cast into the treasure of our purely intellectual wealth. The most rigid advocate of retrenchment cannot object to the moderate provisions which shall exempt such a man in his old age from the irksome drudgery of elementary teaching. It is very desirable that the British government shall be spared the deep reproach which otherwise assuredly awaits it, of having treated with coolness and neglect one who has contributed so much to raise his country high among intellectual nations."

Lord Grey's government granted Dalton a yearly pension of a hundred and fifty pounds, later increased to three hundred. Yet he continued to teach and work in the field of science. In 1837, suffering from an attack of paralysis and unable to go to Liverpool where the British Association was meeting, he communicated a paper on the atmosphere—his first love. He had calculated that the assistance of plants in purifying the atmosphere, by absorbing carbon dioxide in starch making, was not necessary. He had figured that during the last five thousand years, animals had added only one-thousandth of one per cent of carbon dioxide to the air. When he was seventy-six, the Association met in Manchester, his home city, and Dalton was able to attend its meetings. He was still working in his laboratory. "I succeed in doing chemical experiments," he told them, "taking three or four times the usual time, and I am no longer quick in calculating."

Two years later he was still making weather observations. He made entries in his notebook of the readings of his barometer and thermometer for the morning of Friday, July 26, 1844. The figures were written in a weak, trembling hand. Over the

entry "little rain" was a huge blot—he could not hold his pen firmly. This was his last entry. The next morning Dalton was dead, having passed away "without a struggle or a groan, and imperceptibly, as an infant sinks into sleep." Forty thousand people came to witness his funeral procession.

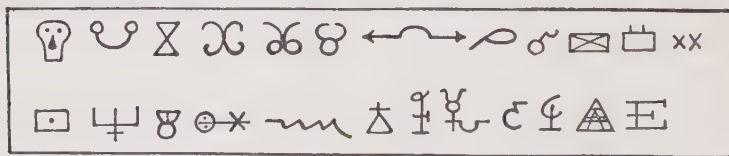
Dumas, the French savant, called theories "the crutches of science, to be thrown away at the proper time." Dalton lived to see his theories still held tenaciously by the natural philosophers of the world. For, "without it, chemistry would have continued to consist of a mass of heterogeneous observations and recipes for performing experiments, or for manufacturing metals." Dalton's Atomic Theory remains to-day one of the pillars of the edifice of chemistry—a monument to the genius of the modest Quaker of Manchester.

VIII

BERZELIUS

A SWEDE TEARS UP A PICTURE BOOK

ONLY the skilled adept could make sense out of the maze of strange pictures and symbols which filled the writings of early chemistry. The alchemists had couched their ideas in an obscure sign language. Perhaps it did not require omniscience to understand that a group of dots arranged in a heap  represented sand. Maybe the connoisseur of wine knew that this symbol  meant alcohol. But who could guess that  meant borax, and  stood for soap, while glass was designated by two spheres joined by a bar ? Clay, to be sure, must be , and this strange sign  meant sea salt. Could  mean anything but a day, and its inverted image  a night? And what of these other strange markings which filled many a manuscript of ancient alchemy, and even found their way into current literature?



What a jumble of meaningless pictures!

The foundations of chemistry were now more or less completed. Phlogiston had been slain, and Lavoisier's theory of burning was safely established. De Morveau's new chemical

nomenclature had been accepted, and Dalton had promulgated his atomic theory, which clearly explained two cornerstones of the structure of chemistry—the Laws of Constant Composition and Multiple Proportions.

But the bog of astrological and occult signs had to be cleared before an enduring edifice of chemistry could safely be raised. The muddle of arbitrary signs had to be destroyed and a more reasonable system substituted for it. The wild belief in alchemy had been scotched, but the serpent still lived, for its symbols still wriggled and twisted over the pages of chemical writings. No amateur could venture alone through its labyrinthine jungles. In one Italian manuscript of the early seventeenth century by Antonio Neri, the metal mercury was represented by no less than twenty symbols and thirty-five different names! In another book, lead was designated by fourteen symbols and sixteen names. Kunkel had rightly complained about this confusion. The old alchemists had tried to hide their pretence of knowledge in the secrets of confused hieroglyphics.

Something had to be done if chemistry was to become intelligible to everyone who wished to study it with reasonable diligence. At about the time that Priestley was discovering oxygen, Olaf Bergman of Upsala had attempted to solve the difficulty. But his figures were almost as barbarous. Still in awe of the ancient masters, he dared not forget them altogether. He continued to use for the metals the ancient symbols that had been handed down from Persia, India, and Egypt, through Greece and Rome to Europe. The number of common metals known to the ancients was seven. This was also the number of planets they had recognized and deified. The Chaldeans, believing that the metals grew by the influence of the planets, had assigned to each god and planet a metal. The Persians represented the revolution of the heavenly bodies by seven stairs

leading up to seven gates—the first of lead, the second of tin, the third copper, the fourth iron, the fifth of a mixed metal, the sixth silver, and the last of gold.

To the Egyptians the circle was the symbol of divinity or perfection, hence it logically represented the sun. The circle was taken also as the symbol of gold, the perfect metal. The moon, seen as a crescent suspended in the sky, gave this planet and its metal silver the symbol of the crescent ☾. The scythe of Saturn, ☿, dullest of the gods, symbolized the character of this heavenly body, as well as lead, dullest of the metals. ⚡, the thunderbolt of Jupiter, was the symbol of lustrous tin. The lance and shield of Mars, god of war, was represented by ♂ which stood appropriately for iron. The looking glass of Venus, pictured thus, ♀, was also the symbol of copper, for Venus had risen full formed from the ocean foam on the shores of Cyprus, famous for its copper mines. Mercury, the speedy messenger of the gods, was pictured with the caduceus or wand ☿.

Bergman clung to these old symbols and introduced a few others like:

	platinum (called silvery gold),		
	nickel,		antimony,
	zinc,		salt,
	arsenic,		sulphuric acid,
	cobalt,		zinc oxide.

An attempt was made to change the ancient sign language. At the time when Lavoisier and his associates were reforming the nomenclature of chemistry, the Academy of Sciences at Paris selected Hassenfratz and Adet to improve the chemical ciphers. Their system, likewise, was too complex. They represented the metals as circles enclosing the Latin or Greek initials of the elements, thus: $\textcircled{\text{A}}$, $\textcircled{\text{P}}$, $\textcircled{\text{H}}$, $\textcircled{\text{St}}$. Burnable bodies they represented by semicircles in four different positions, as follows: $\text{)} hydrogen, \text{) sulphur, (carbon, and } phosphorus$. Three short straight lines in different positions represented caloric, oxygen, and nitrogen. Compound substances whose compositions were still unknown were designated by squares standing on one point. By placing their symbols in different positions, pictures could be made for more than three hundred thousand different compounds, each consisting of three simple substances.

The result was again confusion. For not every student of chemistry was a draftsman. A simpler system was soon devised by a man whose work in the field of chemistry was so eminently successful, that for years he was respected as a lawgiver, a veritable autocrat of the chemical laboratory. In 1796 we find Berzelius at the University of Upsala in Sweden preparing for his medical degree. He was accustomed to hardship. For years this orphan boy had worked on his stepfather's farm, living in a room which, fortunately for him, was also the storehouse of a crop of potatoes. His mean, thrifty stepfather made sure that these potatoes would not freeze during the cold winter. So the warmth that protected them kept the boy, John, alive.

Four dollars and a pair of woolen stockings were his meager pay for his years of service. He had set out for the high school at Linköping near where he was born, dreaming of what he

might become in ten years or so. Perhaps a clergyman. Had not his father, his grandfather, yes, and even his great-grandfather been clergymen, and why not he, John? But he was not to enter the ministry. At school he became interested in nature—more especially in the collection of flowers, insects and birds. He bought a gun and whenever the chance presented itself, he would forget the rigid rules of the school and steal off to hunt specimens of birds. His teacher had encouraged him in this love of natural history, which almost ended in disaster. To keep himself at school he managed, like other students at the gymnasium, to do some private teaching. He was tutoring the two sons of a widow, and in his zeal almost killed one of them with his gun while they were out hunting birds. Widow Elgerus complained to the rector, who instantly forbade him the use of the weapon. But John hated authority as much as he loved shooting. For using the gun on further occasions, he was almost expelled. Besides, he had cut some of his classes. During his last term he had been absent from his Hebrew classes a total of sixty-three hours! The rector did not forget, for when young Berzelius came up for his certificate of graduation, he was warned that he was a young man of good abilities and doubtful ambition and had cut sixty-three hours. He would have to mend his ways if anything creditable was to become of him, for “he justified only doubtful hopes.”

At the University he became interested in experimental chemistry. He had picked up the cheapest textbook he could buy—Girtanner's *Anfangs Grunde der Antiphlogistischer Chemie*, the first German book based on the antiphlogistic chemistry of Lavoisier, and had asked his teacher, Professor John Afzelius, for permission to work in the small laboratory in his spare time. Students were at liberty to work there only once a week, but that was not enough for Berzelius. He pleaded with Afzelius,

who, as a test, tried to discourage him by ordering him to read several voluminous works on pharmacy. This would have checked the most ambitious college student. But Berzelius waded through the mass of involved preparations and hieroglyphics, and once more appealed to Afzelius.

"Do you know a laboratory from a kitchen?" laughed his teacher. Strange that he should have asked such a question, when his own laboratory was but a converted kitchen. Little did he realize that years later, when Berzelius was to do his classic work, his laboratory would also be his kitchen. Afzelius was adamant. "You may come only when the others work," he told him. But even school authorities were not going to stand in his way. He pleaded with the caretaker, even bribed him, and soon found access to the laboratory through the back door when Afzelius was away. For some days John worked in secret excitement performing the textbook experiments and trying some of his own invention. Then one day he was caught. For a while, Afzelius stood in the darkness watching this boy carefully handling all kinds of chemical apparatus. Then he confronted the culprit. He rebuked Berzelius for daring to break the rules of the school. John made no answer. He was picturing expulsion. But Afzelius was only jesting. "Hereafter you must use the front entrance of the laboratory. And you may steal in even when I am looking."

But still Berzelius did not have enough freedom for his own work. He rented a student's room which boasted an adjoining windowless den with a fireplace. Here he spent some of the most exciting hours of his life. "One day," he wrote, "I was making fuming nitric acid and noticed some gas escaping. I collected it over water in bottles to find out what the gas was. I suspected oxygen, and seldom have I had a moment of such pure and

heartfelt joy as when the glowing splint placed in the gas burst into flame and lighted up my dark laboratory."

Then, after a series of painstaking experiments, he prepared a paper on a peculiar gas called nitrous oxide. He presented it to his teacher, who shook his head and sent it first to the College of Medicine and then to the Academy of Science. To the disgust of Berzelius, the paper was refused, not because it was unworthy of an expert experimenter, but "because they did not approve the new chemical nomenclature" of Lavoisier which he had dared to use. Against such scientific inertia did Berzelius have to contend.

In the meantime, while Berzelius was completing his work at the University, Alessandro Volta, professor of physics at Pavia, invented a new machine for producing electricity. This invention like many others was the result of an accident. A few years before, his countryman, Aloisio Galvani, had left some dissected frogs hanging by a copper hook from an iron balcony. As the wind blew the bodies of the frogs against the iron the legs of the dead frogs contracted and wriggled. An almost indescribable phenomenon. Active muscular contractions from the limbs of dead frogs! Galvani was amazed. In his place, another man might have astonished the world with some mysterious explanation of life after death. But he did not explain the phenomenon on the basis of a resurrection. The days of the old alchemy were past.

He made an ingenious but erroneous explanation. Volta set to work to find the true cause of this "animal electricity." Slowly he came to believe that the electricity produced belonged to the metals and not to the frog's legs. He proved it to the astonishment of the scientific world. Furthermore, he made good use of his discovery. By connecting a series of two dissimilar metals, zinc and silver, separated by a piece of cloth moistened

in a solution of salt, he obtained a weak electric current. He joined a larger series of these metals and obtained a stronger flow of electricity. Volta had invented the "voltaic pile," forerunner of the modern storage battery.

Sir Joseph Banks, President of the Royal Society of England, received the first announcement of this discovery in a private letter (March 20, 1800) from Volta who was a Fellow of the Society. Before reading it to the Royal Society in June, Banks showed it to Sir Anthony Carlisle and William Nicholson. These men were not slow to grasp the immense possibilities of this new force. It could, perhaps, be used to disrupt hitherto unbreakable substances. They immediately sent the energy of a voltaic pile through water decomposing it into hydrogen and oxygen which formed at the two platinum poles of their electric machine. Fourcroy, friend and enemy of Lavoisier, built a large voltaic pile and ignited with it hitherto incombustible metals.

The imagination of Berzelius was at once kindled. Here was a mighty weapon for the chemist. He began to work with his oldest half-brother, Lars Ekmarck, on voltaic electricity. His thesis for his medical degree was on the action of electricity on organic bodies. The following year, with his friend, von Hisinger, he published a paper on the division of compounds by means of the voltaic pile, in which he propounded the theory that metals always went to the negative pole and non-metals to the positive pole of the electrical machine. Benjamin Franklin had introduced this idea of positive and negative electricity. He had called a body positively electrified when it could be repelled by a glass rod rubbed with silk.

The work of Berzelius, however, hardly caused a ripple in the chemical stream of progress. But four years later a young chemist in England, reading an account of his works and fol-

lowing them up, fired the imagination of the world. Benjamin Franklin had "disarmed the thunder of terrors and taught the fire of heaven to obey his voice," but now Humphrey Davy, using Volta's electric pile and the research of Berzelius, isolated such new and strange elements as staggered men even more than the discovery of phosphorus a century before.

Potash and soda had been known to be compound in nature, but no method had been found to break them up into their component elements. Davy, in whose laboratory immortal Faraday washed bottles, built a powerful voltaic battery of copper, and in October, 1806, sent the energy of one hundred and fifty cells through some molten potash. He watched for a deep-seated decomposition. At the negative wire of platinum he soon saw globules of a silvery substance spontaneously take fire. "His joy knew no bounds, he began to dance, and it was some time before he could control himself to continue his experiments." He worked so hard that he soon became ill and all London prayed for his recovery.

Fashionable London received Davy's isolation of the metal potassium as another wonder of the world, and he was lionized. People paid twenty pounds to gain admittance to his lectures. The French Academy of Sciences awarded him a medal. Berzelius would have shared this prize had it been known that Davy's discoveries resulted from the previous work of the Swede. This was the statement of Vauquelin, discoverer of chromium.

Once before, Davy, son of a poor woodcarver of Penzance, had achieved overnight fame by his discovery of the physiological effects of laughing gas—that colorless nitrous oxide first obtained by Priestley in 1776 and later described by Berzelius to his teacher Afzelius. Distinguished people in all walks of life had come to London to inhale the gas which had

raised Davy's pulse "upwards of twenty strokes and made him dance about the laboratory as a madman." Even the poet Coleridge was among those who came, but admitted that Davy's epic poem on the deliverance of the Israelites from Egypt had interested him more.

For a long time chlorine was considered to be compound in nature. Berzelius, too, believed this and disagreed with Davy, who considered it an element. Davy's illuminating experiments later convinced the Swede that chlorine was not "oxymuriatic acid," an oxygen compound of hydrochloric acid, but a simple elementary gas. When Anna, his housekeeper, complained that a dish she was cleaning "smelled of oxymuriatic acid," Berzelius now corrected her: "Listen, Anna, you must not say oxidized muriatic acid any more. Say chlorine, it is better."

After this controversy over chlorine Berzelius, now professor of chemistry, biology, and medicine at the University of Stockholm, was eager to meet Davy. However, he had previously received an invitation from Berthollet to visit Paris. While wavering between Paris and London war broke out between Sweden and Napoleon, and Berzelius travelled to England. He met Davy in his laboratory at the newly founded Royal Institution. They spoke about chlorine and the visitor complimented Davy on his important contributions.

He invited his visitor to his house the next morning. Berzelius was ushered into the dining room by the French butler. Davy made him wait there long enough to become fascinated by all its splendor and wealth—he was the husband of a wealthy widow. Then while they breakfasted, the Englishman and the Swedish scientist talked again about chemistry. Davy tried to impress upon his visitor his own eminence. At twenty-two he had been selected by Count Rumford as professor of chemistry at the Royal Institution. At thirty-three he had been knighted

by the King. Fashionable London was at his feet. Berzelius, who was to be the teacher of kings and princes and the recipient of every honor that the chemical world had to offer, found such putting on of airs distasteful. Many years later, while travelling through Denmark and Sweden, Davy visited Berzelius, whom he considered "one of the great ornaments of the age." But a breach between the two chemists occurred soon after, due to the mischief of the secretary of the Royal Society, and they never saw each other again.

Before leaving for home, Berzelius bought much chemical apparatus, and made a trip to visit Sir William Herschel at Slough, where the erstwhile oboist and now celebrated astronomer showed him his great telescopes, whose mirrors he had stood grinding for hours with his own hands while his sister fed him. Then Berzelius visited Cambridge where he wrote, "It was with a feeling of reverence I visited the room where Newton made the greater part of his splendid discoveries." Later, at a luncheon, he spent "one of the most memorable days of my life" when he met, among other distinguished scientists of England, Thomas Young the versatile genius who established the wave theory of light by his discovery of the interference of light. Upon his return, the King of Sweden appointed him Director of the newly established Academy of Agriculture.

Shortly afterwards, Berzelius accomplished one task which did much to make the road of chemical learning easier to travel. Quickly and decisively he abandoned the old sign language of chemistry and introduced in its place a rational system of chemical shorthand. "It is easier to write an abbreviated word than to draw a figure which has little analogy with words and which, to be legible, must be made of a larger size than our ordinary writing." This was the basis of the great change he

had planned when the Swedish Government put him in charge of compiling the new Swedish Pharmacopœia. "The chemical signs ought to be letters for the greater facility of writing, and not to disfigure a printed book. I shall therefore take for the chemical sign," he said, "the initial letter of the Latin name of each chemical element," thus:

Carbon.....	C	Oxygen.....	O
Hydrogen.....	H	Phosphorus.....	P
Nitrogen.....	N	Sulphur.....	S

"If the first two letters be common to two metals I shall use both the initial letter and the first letter they have not in common," as:

Gold (aurum).....	Au	Silicon (silicum).....	Si
Silver (argentum)...	Ag	Antimony (stibium)...	Sb
Copper (cuprum)....	Cu	Tin (stannum).....	Sn
Cobalt (cobaltum)...	Co	Platinum.....	Pt
Potassium (kalium)...	K (written <i>Po</i> for a while)		

A firm believer in the atomic theory of Dalton, Berzelius made his new symbols stand for the relative atomic weights of the atoms. The initial letter capitalized represented one atom of the element. These symbols stood for definite quantitative measurements and "enabled us to indicate without long periphrases the relative number of atoms of the different constituents present in each compound body." Thus they gave a clew to the chemical composition of substances. This was a tremendous step toward making chemistry a mathematical science.

True, William Higgins a generation before had introduced symbols, writing "I" for inflammable air or hydrogen, "D" for dephlogisticated air or oxygen, and "S" for sulphur. He had even suggested the use of equivalent weights of the elements

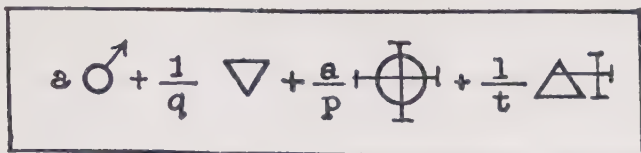
(attractive forces, he called them) expressing the formula of water as "I— $6\frac{5}{8}$ —D" where $6\frac{5}{8}$ represented the equivalent weight of oxygen to hydrogen. But his writings were unclear, his explanations hazy, and he never undertook to generalize his innovations.

Berzelius went further in his attempt to simplify the science. He joined the symbols of the elements to represent the simplest parts of compounds. Thus copper oxide was written CuO, and zinc sulphide ZnS. He had, at first, denoted the number of oxygen atoms by dots and the number of sulphur atoms by commas; thus carbon dioxide was $\ddot{C}$ and carbon disulphide was $\ddot{C},$. But he soon discarded these dots and commas, although for decades after, mineralogists utilized this method of writing the formulas of minerals.

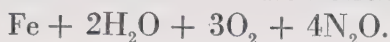
Berzelius introduced the writing of algebraic exponents to designate more than one atom of an element present in a compound. These exponents were later changed by two German chemists, Liebig and Poggendorff, to *subscripts*. Subscripts are small numbers placed at the lower right corner of the symbols of substances where the atoms occur in the compound in numbers greater than one. Thus carbon dioxide, which contains one atom of carbon and two atoms of oxygen, is written CO₂.

These symbols and formulas were first introduced in 1814 in a table of atomic weights published in the *Annals of Philosophy*. Within a few years the literature of chemistry began to show a radical change. Dr. Edward Turner of Union College, London, in the fourth edition of his *Elements of Chemistry*, published in 1832, used these symbols with the apology that he "ventured to introduce chemical symbols as an organ of instruction." Instead of the hieroglyphics of the gold seekers, chemists used the simple system of Berzelius. And what a world

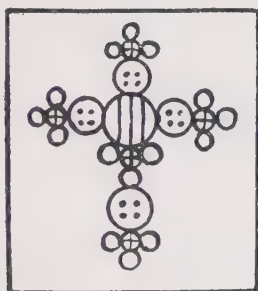
of difference there was between the following symbolic language of Lavoisier:



and this translation of the above in the Berzelian system:



As with every great advance in science, there were objections. Dalton, himself, strangely enough thought his own picture-language superior. "Berzelius' symbols are horrifying," he wrote. "A young student might as soon learn Hebrew as make himself acquainted with them." He must have forgotten his own picture of alum which he represented thus:



where  was sulphur,  potash, and  alumina.

The new system, however, stood the test of time. Not only were the original symbols of Berzelius accepted but they also formed the basis for the naming and writing of newly discovered elements and compounds.

And now Berzelius set himself a still greater task. While working on a new textbook, he came across the work of Richter on the proportions in which substances combine. This started him on an investigation of atomic weights. Dalton's relative

weights of the atoms were both inaccurate and incomplete. The Swedish scientist realized that the chemist must have accurate relative weights if chemical manipulations were to become more than the guesswork of the old alchemists. He was going to find out the relative weights of all the different elements then known. "Without work of this kind," he declared, "no day could follow the morning dawn." At the same time he was ready to put all his indefatigable energy into the work of establishing Dalton's atomic theory by analyzing every chemical compound he could obtain.

Few would have attempted such a colossal task. Think of the time and the conditions under which he worked. In the reminiscences of his famous pupil, Woehler, is a description of the room in which Berzelius labored. "The laboratory consisted of two ordinary rooms with the very simplest arrangements; there were neither furnaces nor hoods, neither water system nor gas. Against the walls stood some closets with the chemicals, in the middle the mercury trough and the blast lamp table. Beside this was the sink consisting of a stone water holder with a stopcock and a pot standing under it. In the kitchen close by, in which Anna prepared the food, stood a small heating furnace." The chemicals he had to use in his analyses were often either unpurchasable or too impure to be used for accurate results.

To-day, with every modern appliance of science at his disposal, many an analyst would shrink from such a stupendous undertaking. But Berzelius did not even waver. He would weigh and measure until he had established the true relative weights of the atoms. To insure accuracy he purified every chemical reagent he used, not once but dozens of times. Even the best apparatus which the chemical world could offer him was still very crude when compared with that of to-day. As he had to



JOHN JACOB BERZELIUS

construct his own apparatus in many cases, he took lessons from an itinerant Italian glassblower, Joshua Vacanno. He devised numerous novel instruments of precision. He invented new processes of purifying chemicals, and changed many practices of analysis then current.

Holidays, distractions, hobbies, even food meant very little to Berzelius during these months of toil. His was an indomitable spirit. Once, while attempting to recover gold from some fulminates, a violent explosion almost killed him. For a month he was forced to remain in a dark room to save his eyesight. When he finally emerged, he went back to his laboratory.

A new observation always gave him great pleasure, and with beaming eyes he would call to his students, "Well, boys, I have found something interesting." When he had to use a platinum crucible he found there was only one in all Sweden. Fortunately von Hisinger was ready to lend it to him. Less lucky with other necessary pieces of apparatus, he had to do without them or invent some other method of analysis. For ten long years, in the midst of teaching and editorial work, he kept analyzing compound after compound, until he had studied the compositions of more than two thousand chemical substances. His blowpipe and balance, his eudiometer and crucible, finally gave him a set of atomic weights of the fifty different elements known to the scientific world of his time.

Compare his list of atomic weights with those of Dalton two decades before him and with the International Table of Atomic Weights of to-day, and marvel at the skill and accuracy of this giant among experimenters.

His numbers were not entirely accepted at first. The British Association for the Advancement of Science was sceptical. Turner was asked to verify the figures and found them to be

	Dalton's Atomic Weights—1808	Berzelius' List 1826	International Table—1930
Chlorine.....	unknown	35.41	35.457
Copper.....	56	63.00	63.57
Hydrogen.....	1	1.00	1.0078
Lead.....	95	207.12	207.22
Nitrogen.....	5	14.05	14.008
Oxygen.....	7	16.00	16.00
Potassium.....	unknown	39.19	39.10
Silver.....	100	108.12	107.88
Sulphur.....	13	32.18	32.06

correct. Later Jean Stas, a Belgian chemist, found an error in the atomic weight of carbon. Berzelius' whole list began to be questioned. Experiments were started in many of the chemical laboratories of Europe to find other errors, but the results only vindicated the experimental exactitude of Berzelius. Some have attempted to rob him of this glory by crediting the remarkable agreement of his figures with those of the present day to a fortunate balancing of experimental errors. The fact remains, however, that his Table of the Atomic Weights of the Elements still stands as a record of skilful manipulation and extraordinary perseverance.

In 1816 Gahn, an industrial chemist, though past seventy, persuaded Berzelius to join him in the purchase of a chemical factory at Gripsholm. In the course of this undertaking Berzelius discovered the element selenium while examining sulphuric acid. He did not remain here very long, for fire soon destroyed the factory. This was not his only industrial venture. He joined A. G. Werner, Professor of Mineralogy at Freyberg, in a mineral water business and later attempted, with borrowed capital, the commercial manufacture of vinegar. But he was no

business man. His ventures all ended disastrously, and it took Berzelius ten years of tireless work to repay his enormous debts.

He undertook extensive editorial work¹⁰ and worked long in his laboratory. Berzelius was as a rule cheerful, Woehler reports, and during his work "he used to relate all sorts of fun, and could laugh right heartily over a good story. If he was in bad humor and had red eyes, one knew that he had an attack of his periodic nervous headaches. He would shut himself up for days together, ate nothing and saw no one." Never-ending work, no relaxation, a life of solitude, had sapped his health. His pains in the head Berzelius curiously associated with the phases of the moon. He seemed to suffer most between eight in the morning and eight in the evening on the days of full and new moon. On one occasion, in Paris, he was invited to attend a dinner. Laplace, the astronomer, sceptical of the Swedish scientist's association of headache with the moon's position in the heavens, had sent him the invitation as a test, believing that the Swede could not possibly know the day of the new moon in a foreign country. Yet Berzelius had to refuse the invitation because of a severe headache.

Before very long he was back in Stockholm, working again in his laboratory, and taking occasional excursions, until his health became so poor that he could not handle his apparatus. Berzelius was now the most eminent chemist in all the world. He was called upon to fill all kinds of honorary positions. An outbreak of cholera in Stockholm in 1834 found Berzelius chairman of a committee superintending the burial of the victims of the deadly epidemic. At five every morning, he was at the graveyard, until one morning a severe cold weakened him so that he lost all desire to live. He was aging, sick and terribly lonely.

Berzelius comes to his friend Count Trolle-Wachtmeister to talk about a subject which, until then, has seldom worried him. The Count listens tenderly to the old man and then advises him: "I suppose one can be quite happy without entering into the married state, but he who has never experienced the happiness of having a beloved wife by his side knows nothing of the finest side of life." Berzelius' eyes brighten and he asks a very personal question. "By a judicious choice it is not too late to enjoy this experience," is the answer. Berzelius is reassured but he must ask another question. "To be perfectly happy," replies his friend, "a man should have a *chez soi* and he ought not to look for it outside his own dwelling." Plain words and to the point.

Many years back, while he was still young and had just thrown himself into the fascinating work of a chemist, Berzelius had thought about marriage. One of his foreign friends, a scientist, was happily married. To him he had gone for advice. "Could a man divide his time between the strenuous work of the laboratory and the responsibilities of domestic life?" The answer he received had helped him to decide. "Although I am as happy as only the father of a family can be," his friend had told him, "I believe that if I were now unmarried, I should certainly not marry except under the influence of an unconquerable passion." Berzelius chose the path of whole-hearted devotion to science. Willingly he followed the lure of the laboratory.

But things were different now. His health was very poor and he was lonely. Count Trolle-Wachtmeister's words were balm to his aching soul. The aged chemist lost no time. He visited the town councillor, his old friend Poppius, who, he knew, had a daughter just twenty-four years old. Hesitating, and fearful of the answer, Berzelius asked him for the hand of his beautiful

daughter. Great was his surprise when not only the parents showed delight, but the girl herself exhibited no displeasure at the thought. For was he not the most distinguished chemist of Europe? Students flocked to him from all over the world. Even kings came to him to learn his science. Sweden's King and Crown Prince were among his pupils, and the Czar and Prince of Russia came to visit him in his laboratory. A signal honor to be the wife of such a celebrity!

Encouraged in his suit, Berzelius must first regain his lost health. He visited Paris and was introduced to King Louis Philippe who talked to him for fully an hour, while the heir apparent, Ferdinand, Duke of Orleans, flattered him by saying that he had received his first lessons in chemistry from the pages of a French edition of Berzelius' *Lehrbuch der Chemie*. In Austria he met Metternich, and at Eger he received a luncheon invitation from the poet Goethe. More than fifty years back Goethe, as a lad of nineteen, had become interested in chemistry while at Leipzig, and had built himself a little blast furnace in which he labored to make alchemic gold and medicinal salts. He soon abandoned this futile pursuit to engage in more practical science. He bought a laboratory and undertook the analysis of well water. At thirty-five this poetic dreamer developed an interest in osteology. While at Jena in 1787, he was comparing human and animal skulls with his friend Lodi, when he hit upon the right track. "Eureka!" he cried, "I have found neither gold nor silver but the human intermaxillary jaw bone." This discovery stunned the world. This bone had heretofore been known to exist only in animals. It had distinguished man from the ape. What a flood of discussion was started by this dilettante in science! Once again science heard of him when, seven years later, he stood brazenly alone to

attack the color theory of Newton. Single-handed he fought every hoary-bearded physicist of Europe with his own conception of color as a combination of light and shadow. He, too, had refused to accept the atoms of Dalton.

Goethe's interest in science was lifelong. The great poet and the great chemist Berzelius walked arm in arm to an extinct volcano whose origin and nature they discussed. Goethe had been interested in the phenomenon of volcanic eruptions and many years before had written a pamphlet on this subject, claiming that no lava would be found in the crater of the volcano. Berzelius believed that if they dug they would find lava. This turned out to be the case and the poet was pleased. Goethe asked him to stay another day, for he wanted to watch Berzelius work with his blowpipe. He marvelled at the skill of his guest, and expressed the regret that, at his age (he was now over seventy), it would be impossible to become an expert even with the help of Berzelius.

At fifty-six Berzelius, stout, middle-sized, of a pleasing personality and polished manners, married the eldest daughter of Poppius. Napoleon's former marshal, Bernadotte, then Charles XIV, King of Norway and Sweden, sent him a personal letter extolling his greatness. He was created a baron and elected member of the Upper Chamber of the Swedish Diet. In 1840 when he was sixty-one, the Diet voted him two thousand dollars as an annual pension. His marriage proved a happy one, and instead of forsaking the strenuous work of the chemist, as Davy had done, he continued to make important contributions from his laboratory. Although, toward the close of his life, some of his generalizations were discarded, yet in his two hundred and fifty papers covering every phase of chemical work he gave to posterity an abundance of facts from which the world long continued to gather rich harvests.

IX

AVOGADRO

THE SPIRIT OF A DEAD MAN LEADS A BATTLE

“THE devil may write chemical textbooks,” Berzelius had remarked, “because every few years the whole thing changes.” Chemical books once more had to undergo a radical revision, for down in Turin, Italy, an unknown professor, thinking about the atom of John Dalton and certain behaviors of gases, had seen a great truth behind them all. His brilliant conception became the starting point of a new development in chemistry and, in a way, bears the same relation to chemistry that Newton’s Law of Gravitation does to astronomy.

This hypothesis, fully explained, he had published in 1811 in a scientific magazine. Within the leaves of this *Journal de Physique* it remained for half a century while verbal controversies raged over dubious points, and the dust of the disturbances settled thickly upon the volume that held a hidden gem.

Had the scientific world seized upon this conception and understood its full meaning, chemistry might have been advanced by decades. But its formulator was an unknown, and he had introduced a new word which chemists were afraid to accept. Had not Dalton stated that the atom was the simplest particle of matter? Then why listen to the dreams of this Professor Lorenzo Romano Amedeo Carlo Avogadro di Queregna e di Cerreto who spoke of little masses of matter which he called *Molecules*!

With the passing of the years, atomic weights and formulas

became more confusing than ever. Now and then the results of quantitative experiments seemed to belie the accepted atomic weights of the elements. To this teacher in Turin, however, everything was clear. His theory seemed to explain all the apparent inconsistencies. And it was so simple! No wild speculations. No involved formulas. No incredible dogmas. Amedeo, the beloved, kept teaching his classes about his molecules. He was not a Berzelius, czar of all the chemical world, nor was he a crusader. He would not storm the scientific world to accept his theory. His students understood him clearly. That satisfied this unambitious teacher. Others would find their way to his conception soon enough. So why not wait? And the chemical world waited.

In 1860 chemical science was in a turmoil. Berzelius, the venerable lawgiver of chemistry, was dead. Chaos prevailed. Karl Gerhardt, breaking with his father who wanted him to work in Strassburg at the manufacture of white lead, came to Paris and wrote a book explaining apparent inconsistencies in the established atomic weights. A radical young Frenchman, Auguste Laurent, assayer of the mint of Paris, attempted a new classification. Professor Petit, another Frenchman, dying at the age of twenty-nine, left a research on the specific heats and atomic weights of the elements which startled the scientific world. Atomic weights, molecular weights and equivalent weights of the elements were all in a muddle. Dalton had said one thing and Berzelius another. Whom was one to believe?

The cry for order was finally lifted above the clash of contending theories and explanations. In September, 1860 there gathered at Karlsruhe the lights of the chemical firmament. From all corners of the world they came. The crisis had to be met, and the clearest minds must attempt to settle it. From France came Béchamp and Wurtz, then professor of chemistry

at the Sorbonne. Anderson, Frankland and Roscoe represented England. Germany, too, sent her chemical mentors—Liebig, Woehler, Mitscherlich, Erdmann, Erlenmeyer and Bunsen. Russia delegated her Mendeléeff. And from Italy journeyed one who had sat in the classroom of Karl Gerhardt listening to his new system of chemistry. He had come not to speak for Gerhardt, but to bring the message of his countryman, the great, modest teacher, Amedeo Avogadro, who four years before had passed away in Turin.

The hundred and forty chemists who had gathered fraternized first at a banquet laid in the large hall of the museum. Chemistry was forgotten for the moment, as they sat eating and drinking, and listening to the wit of that cosmopolitan assemblage. The next morning Boussingault, pioneer investigator of the composition of milk, was elected President for the day. The secretaries had prepared a number of questions for general discussion: Would it be judicious to establish a difference between the terms atom and molecule? Were atoms and molecules entirely different? Would it be judicious to designate by the term molecule the smallest quantity of a body capable of entering into chemical combination? Should the *compound atom* of Dalton be entirely suppressed?

Kekulé of benzene fame spoke first. He was willing to accept the term molecule as distinct from the atom but with reservations. He insisted upon a clear distinction between a *physical* molecule and a *chemical* molecule. Wurtz, Miller and Persoz joined in the discussion. Instead of clarifying the question, an interminable debate ensued in which divergent points of view further confused the animated controversy.

Then the bearded young Italian rose to add his voice to this momentous debate. In the eyes of Stanislao Cannizzarro was the glint of a brave crusader. This man had led a colorful life. At

fifteen he was studying medicine at the university of his native city of Palermo in Sicily. He then, like Berzelius, turned to chemistry, and went to the University of Pisa and from there to Naples.

Sicily was sizzling with rebellion. The government of the ruling Bourbons was oppressive. A wave of nationalism was sweeping over Italy, led by Mazzini, founder of the revolutionary society of "Young Italy." When Cannizarro heard of a political insurrection at home, he rushed from his laboratory to join the nationalist leaders in Sicily. A warm reception greeted this boy of twenty-one. He became an artillery officer at Messina and was chosen deputy to the newly organized Sicilian parliament. The revolution, however, proved abortive and Cannizarro was obliged to flee to France. His father had been Inspector General of Police in Sicily, and young Cannizarro knew more than the foreign officials thought safe.

From Marseilles he went to Paris and finally found his way to the little chemical laboratory of Michel Chevreul, the grand old man of chemistry who was to live through one hundred and three years of chemical progress. Cannizarro threw himself again into the work of chemistry with the same enthusiasm he had displayed as revolutionist. He never left his beakers and test tubes except to go occasionally to the College of France. Soon he accomplished a research of the first importance—the preparation of cyanamide.

When the political horizon had cleared in his own country, Cannizarro returned to teach. As professor of chemistry at the National College of Alessandria in northern Italy, he brought to this seat of learning the scientific knowledge of France, England and Germany. For the first time his students heard clearly about the odd atoms of the Manchester schoolmaster. Eagerly they listened to this charming teacher lecture about Avogadro's

assumption, and of a new method of determining molecular weights. This was all new to them! They were fascinated by the clarity and vivacity of this firebrand. In his enthusiasm he would often forget to dismiss his class on time. When his students reminded him of the lateness of the hour by gently tapping with their feet on the floor, he would smilingly admonish them not "to use the language of beasts." How different he was from their old teachers! The city officials approached him about popular lectures for the general public. Cannizarro was willing, and his special talks on chemistry, citizenship and operas delighted his audiences.

Four years later Cannizarro occupied the chair of chemistry at the University of Genoa, birthplace of Mazzini. While here he married an English lady, Henrietta Withers. Again exciting news reached him. The Sicilians once more had rebelled against their king, Francis II of Naples. On May 11, 1860 one thousand Red Shirts, led by Garibaldi, landed at Marsala to do battle with twenty-four thousand royalist troops. It was an audacious invasion. Garibaldi, hero of Montevideo and candle-maker of New York, forced his way to Palermo and triumphed by sheer courage. Cannizarro was thrilled. He immediately joined a second expedition and landed safely in Sicily. But it was too late. The fighting was over—Sicily was free. He rushed to Palermo to meet his mother and sister whom he had not seen since the stormy year of 1849.

In the midst of these political struggles, Cannizarro received an invitation to attend the Congress of Karlsruhe. As scientist, too, Cannizarro was a champion of reform. He was eager to bring the message of the modest Turin professor who was now dead and forgotten. To him this was as important as the unification of Italy or the *Origin of Species* which Darwin had just published. In an impromptu speech of sparkling eloquence, this

young orator of thirty-four combated the ideas of Kekulé and the other chemists who had not seen the light. The world knew little of molecules as conceived by Avogadro. The word had been used since the seventeenth century but it was synonymous with the atoms of the ancients. Scientists had spoken of atoms of hydrogen, an elementary substance, and atoms of water, a compound substance, without distinction. Later they had made some differentiation between the simple atom of oxygen and the compound atom of water. Dalton had been responsible for another blunder. He had used atom and molecule interchangeably.

Amedeo Avogadro had made a bold guess to explain certain facts of gaseous reactions. He had that piercing glance which sees through difficulties that others cannot penetrate. He had caught a glimpse of a truth and followed it through unafraid. A molecule, according to him, consisted not of a *single* atom but of *two* or more atoms chemically combined. Hence a molecule of certain gases was larger than an atom. Cannizzarro had studied the work of his countryman. He was convinced of the validity of Avogadro's hypothesis. Perhaps Avogadro's theory had received scant attention because his molecules were not clearly understood. He used the term molecule either alone or with a qualifying adjective. His *integral* molecule meant the molecule of any compound, while his *constituent* molecule referred to the molecule of an elementary substance. Cannizzarro clarified the whole situation.

The new molecule of Avogadro promised tremendous improvements in chemistry. Cannizzarro knew that Avogadro's molecule would have to fight its way into the society of Dalton's atoms. His voice rang out clear. He made an heroic fight for what seemed a lost cause. He pleaded for the admission of the molecule into its honored place as a worthy peer of its tinier

relation. He was certain that Avogadro belonged to the category of illustrious Italian scientists of the breed of Galileo, Torricelli, Volta and Spallanzani.

His audience was lukewarm. Just then Jean Baptiste Dumas of the French Institute appeared in the hall. Tumultuous applause greeted his entrance. Dumas, the dean of French chemists, thirty years back, was one of the very few who had read Avogadro's views, but saw in them only a vague promise, for the world was not ready for them. "We are yet far away," he had declared, "from the time in which molecular chemistry will be founded on sure rules. Let us hope for a near and lasting revolution in this direction." He had come unsuspectingly to witness this revolution. The assembly again applauded wildly as, escorted by the commissioner general, he took a seat near the President's chair. No such loud tribute, not even a single hand-clap, had been heard at the mention of Avogadro's name.

Another day of debating followed. Again endless discussion, conflicting opinions, and the Congress was ready to adjourn. Dumas thanked the general commissioner for the zeal with which he had organized the meetings, and begged Weltzien to express to the Grand Duke, who was absent from Karlsruhe, the thanks of the members. Then, without accepting any general principle for which purpose they had met, the chemists returned home.

But this conference was not a colossal failure. Two years before Cannizarro had come to Karlsruhe he had written a long letter to his friend, Professor S. de Luca. This letter was later published as an *Outline of a Course in the Philosophy of Chemistry*, based on the theory of Avogadro. Reprints of this *Sunto di un Corso di Filosofia Chimica* were distributed by Cannizarro at the close of the Congress. It had originally met with scarcely any notice, but Cannizarro had hopes that some

might see the light. One of the younger chemists who attended the meeting, Lothar Meyer, put a copy of this pamphlet in his pocket. On his way home he read and reread it. "It was as though the scales fell from my eyes," he wrote. "Doubt vanished, and was replaced by a feeling of peaceful clarity." He, at least, had caught the missionary spirit of the Italian. Four years later he incorporated Avogadro's ideas in his *Modern Theories of Chemistry*, and in 1891 Cannizarro was awarded the Copley Medal of the Royal Society for this *Sunto*.

Odling, who had likewise heard the impassioned words of Cannizarro, included his atomic weights in a manual of chemistry but neglected even to mention Avogadro. Hermann Kopp, the leading historian of chemistry of the time, had not even heard of the Italian professor when he wrote his classic *History of Chemistry* fifteen years before the conference. Now, however, in a new edition he made mention of his contribution. Seldom had a man been so entirely neglected as was Amedeo Avogadro.

Here was a tool which unlocked many of the mysteries of atomic weights and formulas, yet its originator had been completely overshadowed for more than fifty years. What kind of man could the creator of such a speculative theory be? Strangely enough, Amedeo was educated to follow not the imaginative ideas of idle dreamers but, like his father, Philippe, the practical logic of the legal profession. He received his baccalaureate degree in jurisprudence at the age of sixteen and his doctorate in ecclesiastical law at twenty. For three years he busily practiced law. Then suddenly he turned to natural science. This young dreamer with kind, expressive eyes was sick of petty squabbles and the frauds of the local law courts. There were finer ways to pass one's life. Deeply interested in chemistry, physics, mathematics and philosophy, he spent years in their study. He soon attracted attention when, with his brother Félice,

he presented to the Academy of Sciences of Turin a memoir on a problem connected with the newly discovered galvanic current. In 1809, at the age of thirty-three, he was appointed professor of physics at the Royal College at Vercelli. When his classic paper on molecules was published in 1811 not a single scientist of the world commented upon it. Even the many-sided Berzelius never heard of Avogadro or his theory. Men were stirred in that year by the accidental discovery and isolation of the element *iodine* by Courtois. The molecules of the Italian professor were not even mentioned.

Avogadro kept teaching and experimenting. He could handle a flask and a balance as well as dream. He measured the increase in the volume of various liquids when they were heated. He studied capillary action, the tendency of liquids to rise in narrow, hair-like tubes. Other problems of physical chemistry occupied his attention outside the classroom. Then in 1820 King Victor Emmanuel I instituted a chair of mathematical physics at the University of Turin, and the versatile scholar Avogadro, who besides Greek and Latin knew German and English, was honored as its first occupant.

He did not hold this position very long. A bloody revolution against the foreign oppressors broke out in Naples. Before it was snuffed out, Piedmont, too, rose in rebellion and demanded a war against Austria. King Victor Emmanuel I abdicated rather than yield to the demands of the revolutionists. His brother Charles Felix succeeded him. The new king was a despot. The uprisings were suppressed and the doors of the University of Turin were closed. Avogadro himself took no part in these stormy affairs. He was a peaceful, pious man. He was given a meager annual pension of about a hundred dollars and the honorary title of Emeritus Professor. But Avogadro could not remain idle. He resumed the practice of law and

continued his study of the sciences. Ten years later, Charles Felix died and Charles Albert succeeded him. Mazzini pleaded for greater freedom. The new king was more liberal and was ready to listen to Young Italy. The University of Turin was reopened, the chair of science restored, and Avogadro was re-instated. He continued to teach for another twenty years. At the age of seventy-four he was finally retired and spent the remaining six years of his life in unhampered study and meditation.

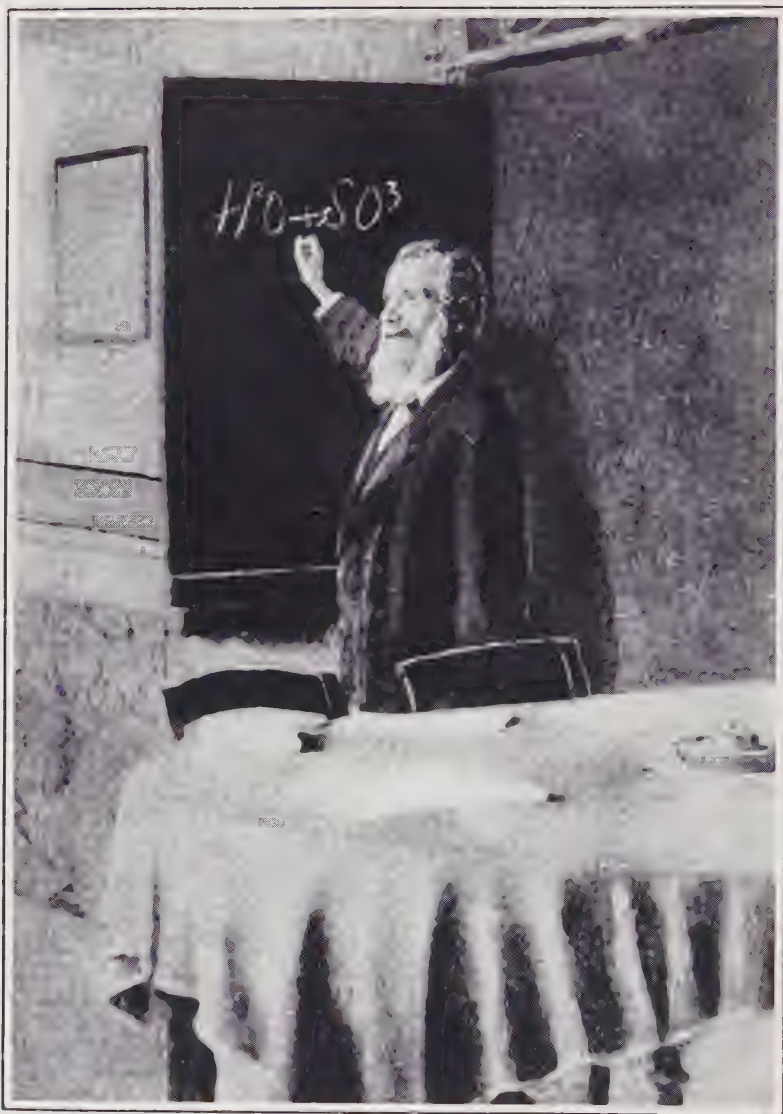
Avogadro had married a lady of Biella by whom he had six sons. Luigi rose to the position of general in the Italian army, and another son, Félice, became president of the Court of Appeals. The quiet professor found time to take a fairly active part in the life of his community. Like Lavoisier, he held many offices dealing with public instruction, meteorology, weights and measures, and national statistics. Unlike Lavoisier, however, he lived a very peaceful, uneventful life, until death called him away at eighty. Not a word of eulogy was pronounced at his simple bier. Only brief obituaries appeared in a few scattered scientific journals filled with accounts of the discovery of the first skeleton of a Neanderthal man; of mauve, the first coal tar dye discovered by Perkin in Hofmann's laboratory in London; of a blast furnace for making steel designed by Bessemer. Not a single word about his monumental memoir of the molecules—a glaring example of the neglect of genius.

When a bust of Avogadro was unveiled a year after his death, not a chemist was there to utter a word of homage. Even in his own country he was little known. Only two of his pupils, both physicists, recalled his work. His classic theory of the molecules had appeared originally not in Italian but in French. It was later translated into both German and English and, al-



AMEDEO AVOGADRO

Bust in the hall of the Scuola Professionale of Biella near Turin



STANISLAO CANNIZZARRO
In his classroom in later life

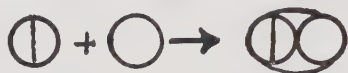
most incredible, was not available in his own language until the opening of the twentieth century. So extremely modest and retiring was this Italian professor that, great as were his contributions in the field of science, when the Scientific Congress met in his own native city, he was not even nominated an officer of that body.

What was the need of the infinitesimal molecule that Avogadro had conjured up out of his meditations? To grasp its real significance we must go back to a memoir which Gay-Lussac had read to the Philomathic Society on the last day of the year 1808. Gay-Lussac at twenty-five had been introduced to the eminent naturalist, Alexander von Humboldt. They met at the home of Berthollet in Paris and discussed the composition of water. Together they experimented and found that two volumes of hydrogen gas when sparked with one measured volume of oxygen gas produced exactly two volumes of water vapor. This was not an original discovery, but Gay-Lussac suspected that "other gases might also combine in simple ratios." Resuming his researches, he discovered that one volume of hydrogen chloride gas when brought in contact with one volume of ammonia gas yielded a white powder, and no residue of either gas was left. The two gases had joined volume for volume. He tried combining carbonic acid gas and ammonia and again found that exactly one part of odorless carbon dioxide had combined with exactly two volumes of suffocating ammonia. His friend Berthollet had shown that a measured volume of nitrogen gas always united with three times its volume of hydrogen to form exactly two measures of ammonia.

Here was a remarkable mathematical simplicity. The combining volumes of gases and the volumes of their gaseous products, could always be expressed in ratios of small whole

numbers. No fractions or large numbers were involved. This was the law discovered by Gay-Lussac.

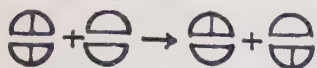
Why this regularity? Was this another example of Nature's striving for simplicity? How could it be explained? Dalton's atoms helped to clarify the question. But here was a fact that even Dalton's little atoms could not explain. Why did one volume of nitrogen unite with one volume of oxygen to yield *two* volumes of nitric oxide gas? Why *two*? Dalton's diagrams showed the formation of just *one* volume of nitric oxide by the union of one atom of nitrogen and one atom of oxygen, thus:



Dalton was asked to explain this inconsistency. He could not fit Gay-Lussac's results into the scheme of his Atomic Theory. He must either alter his theory or reject the conclusions of the Frenchman. He saw no other way out of the dilemma. Dalton, the clumsy experimenter, refused to admit the validity of Gay-Lussac's Law. "The truth is," he maintained, "that gases do not unite in equal or exact measures in any one instance; when they appear to do so, it is owing to the inaccuracy of our experiments." Berzelius knew that Dalton was wrong. He wrote to Dalton: "I think there are parts in your theory which ought to be altered. For instance, that part of it which leads you to assert that the experiments of Gay-Lussac on the volumes of combining gases are inexact. I would rather have supposed that these experiments form the most beautiful proof of the probability of the atomic theory." Dalton could not be convinced and the result was utter confusion.

Another effort was made to bring Gay-Lussac's Law and Dalton's Atomic Theory into harmony. It occurred to some scien-

tists to split the atom in two and thus avoid the difficulty. Thus:



would yield the *two* volumes that Gay-Lussac found and not the single volume that Dalton's theory would compel one to accept. Chemists were desperate. They were ready to agree to any explanation. Dumas himself was willing to break the unbreakable atom of Dalton into quarter atoms. When his friends objected to this scientific sacrilege Dumas quietly answered, "Chemistry must break apart the atom which physics cannot split. That is all there is to it."

Avogadro alone saw the error that confused the scientific world. He could reconcile the atomic theory of Dalton and Gay-Lussac's law of combining volumes of gases. To him the smallest part of a common elementary gas like hydrogen consisted not of one atom, but of *two* atoms chemically united. This pair of hydrogen atoms he called the *molecule* of hydrogen. Gaseous hydrogen was not H but HH, or H_2 as Berzelius wrote it. In other words, a gas was made up not of single atoms but of groups of atoms called *molecules*. To be sure, Berzelius had spoken of certain elements which seemed always to take part in chemical reactions in pairs of identical atoms, and he had represented them with the symbol of the element with a bar drawn across it, thus: $\overline{E}$. The Congress of Karlsruhe had, in fact, accepted the dashed letters of Berzelius to express "double atoms." But this had by no means cleared up the matter.

Avogadro had reached his conception of pairs of atoms which combined to form molecules by postulating an audacious theory. "*Equal volumes of all gases,*" he declared, "under the same conditions of temperature and pressure contain the *same number of molecules.*" A given volume of any gas, be it simple hydrogen, or compound carbon dioxide, contained the same definite number of molecules. Avogadro's hypothesis was the

conclusion of a meditative mind bold enough to fly beyond the limits of the experimental verifications of the balance and the microscope. While he left no positive evidence of the genesis of his hypothesis we may safely believe that he made and rejected numerous assumptions before he finally reached his conclusion.

What evidence had he to back up so bold a statement? He had not tested it in the laboratory. He could not verify it. No balance was sensitive enough to weigh the molecule. For it would take billions upon billions of these tiny particles to turn the scale of the most delicate balance in the world. He surely had not looked into the molecules of matter and detected a twin arrangement of the atoms. For it would take one hundred millions of his molecules placed side by side to make a line one inch long. No microscope had as yet been devised to make such an infinitesimal particle visible. Even had he built a mighty instrument that could magnify the molecule to the limits of human sight, his head would have reeled at the tremendous speed of these tiny molecules flying with a velocity three times as great as that of a bullet leaving the muzzle of a rifle, and colliding five thousand million times per second with neighboring molecules. Stupendous speed of an infinitesimal body!

His theory, when he postulated it, was only a fabrication of the brain. Small wonder that the ears of the world were shut to his announcement. Yet Avogadro did not wrestle with particles millions of times smaller than the head of a pin in the same stupid way that the ancients fought over the number of angels that could dance on the point of a needle. His was the judgment of scientific thinking. One century of advance in physics and chemistry has testified to the truth of his great guess. While at the congress of chemists at Karlsruhe Cannizzarro was pleading for his molecules, Clerk-Maxwell, developing the Kinetic

Theory of Gases, made the first estimate of the number of particles in one cubic centimeter of a gas. Avogadro's theory was mathematically verified. A mere coincidence, some said. A great work of genius would be the truer and more generous verdict.

Almost one hundred years later, the son of an artillery officer of Lille, France, sat down before a powerful microscope to test by actual experiment the truth of Avogadro's hypothesis. Did equal volumes of all gases really contain the same number of molecules? Other scientists before him had tried to verify it with ingenious schemes. They had beaten gold into sheets so thin that four hundred thousand made a pile hardly an inch thick. They blew soap-bubbles one-billionth of an inch thick. Each film of gold and bubble of soap must be still several molecules thick or it would not hold together. A single pin-point of indigo colored a ton of water. They were getting nearer to the size of an actual molecule.

Jean Baptiste Perrin, the molecule counter of the University of Paris, followed a different method of attack. He prepared the finest powder in the chemical world from the gum gamboge, and placed a weighed amount of this gum in water. It did not dissolve but the fine particles scattered themselves throughout the water. For three whole weeks this suspension was violently agitated until the heavier particles of gum settled to the bottom and were removed. Only the tiniest grains of the powder remained suspended in the water.

Perrin placed a drop of the water containing the fine particles of gamboge on a slide under the microscope. A powerful beam of light illuminated that drop. Every time a speck of gamboge passed across the field of his microscope he saw a momentary flash of light. Hour after hour and day after day he sat recording these flashes. Weeks passed, and still he kept

watching the infinitesimal particles. It was an eye-straining, head-splitting job, but this Frenchman kept on. He counted the number of specks of gamboge—he knew the weight of gum he was using. Then he made his calculations. The number of molecules in a cubic centimeter of a gas was 31,500,000,000,000,000,000. A staggering number! He checked his results. He tried another suspension—mastic gum in alcohol. Again the same result.

Then Professor Robert Andrews Millikan of the University of Chicago, using an entirely different method, obtained an almost identical figure: 28,500,000,000,000,000,000. What does this number mean? It takes a clock three hundred years to tick one billion. Yet there are, Perrin found, thirty billion, billion molecules in a single tiny thimbleful of a gas. This was no idle guess. Perrin and Millikan, both Nobel Prize winners in physics, maintain that we can count the number of molecules in a small volume of a gas with as much accuracy as we can determine the population of a city like New York! Then came another remarkable verification. Dr. Irving Langmuir dissociated the hydrogen molecule at very high temperatures and found it actually to contain two atoms.

What was the immediate importance of Avogadro's theory when Cannizarro proclaimed it to the world? The acceptance of this generalization cleared the scientific air like magic. Inconsistencies, conflicting opinions, impossible conventions and compromises were at once obliterated. Chemistry was again ready to advance.

This conception made possible the true understanding of the atomic weights of the elements. "Instead of taking for your unit of atomic weight the weight of an entire molecule of hydrogen," said Cannizarro, "take rather the half of this weight, that is to say, the quantity of hydrogen contained in the mole-

cule of HCl." When this was done the first accurate table of atomic weights was obtained.

Gay-Lussac, in his memoir, had expressed the hope that "we are perhaps not far removed from the time when we shall be able to submit the bulk of chemical phenomena to calculation." Avogadro's contribution to chemistry showed the way. It led also to a final agreement as to the true formula for water.

Dalton had written the formula for water as  since he believed that *one* atom of oxygen combined with *one* atom of hydrogen to form *one* atom of water. Thomas Graham, founder of colloid chemistry, as late as 1850 used the formula HO in his textbooks. In our own country in 1863, Edward L. Youmans in his *Class Book of Chemistry* declared there were reasons for believing that the true formula for water was H₂O₂ and not HO. Now for the first time the formula for water was definitely established as H₂O.

Avogadro's hypothesis was of inestimable help in determining the density and molecular weights of a large number of gaseous products prepared during the rapid development of organic chemistry. This, in turn, resulted in the marvelous strides that were made in the study of the molecular composition of the most complex chemical compounds. His theory showed that the elementary gases, like oxygen, hydrogen, chlorine and nitrogen, all contained two atoms to the molecule, and that, therefore, their molecular weights were twice their atomic weights, ignorance of which had led to innumerable difficulties. Avogadro's theory was found to be almost universally applicable. Later the Dutch scientist van't Hoff extended its application to the problem of solutions.

Cannizarro worked a lifetime to bring Avogadro back to the world. Then at eighty-four, still teaching and editing an Italian

chemical journal, the crusader of Palermo passed quietly away in Rome. The following year, on September 24, 1911 an historic meeting took place in Turin to commemorate the hundredth anniversary of the publication of Avogadro's classic memoir. King Victor Emmanuel III was there to pay homage to one of Italy's most illustrious sons. Hundreds of scientists gathered there. Messages and money were pouring in from every scientific laboratory of the world. A monument to the memory of Avogadro was unveiled.

From America, France, Germany, Sweden, England, Spain, Austria and Japan came cablegrams and letters extolling the genius of this Italian professor. Anxious to atone for its grave neglect, the world joined in one of the greatest posthumous tributes to a scientist in history.

"Equal volumes of all gases under the same conditions of temperature and pressure contain the same number of molecules"—this one clear prophetic sentence has immortalized the name of Amedeo Avogadro.

X

WOEHLER

UREA WITHOUT A KIDNEY

ONE hundred years ago an epoch-making event took place in the laboratory of a young German still in his twenties. He had just returned from the laboratory of Berzelius in Stockholm, to teach in the newly founded municipal trade school in Berlin. A great idea was hatching in Friedrich Woehler's head. He had heard discussions in every scientific circle he had visited of a mysterious vital force, as elusive as phlogiston.

Inside the living body of plants and animals, it was thought, burned a steady invisible flame, and through this flame a mysterious vital force built up the sugars, the starches, the proteins and hundreds of other very complex compounds. This vague creative force existed in the animal and vegetable kingdoms but not in the mineral world. Men believed that the substances which constituted the texture of vegetation differed from mineral substances in that the former could not be built up or synthesized in the laboratory. "Nothing but the texture of living vegetables, nothing but their vegetating organs, could form the matter extracted from them; and no instrument invented by art could imitate the compositions which are found in the organic machines of plants." Man could never imitate the power of this vital force. It was one of those mystic causations of which man was to remain in ignorance all the days of his life. Man's mental machinery and his chemical engines were too puny and simple to reproduce this force of nature.

Some even doubted whether these organic compounds obeyed the laws of chemistry. Such was the prevailing opinion of the world in 1828.

Berzelius himself spoke of the impassable gulf which separated organic compounds from inorganic substances. Leopold Gmelin, Friedrich's celebrated teacher at the University of Heidelberg, firmly believed that organic compounds could not be synthesized. Yet Woehler was young and he doubted. He agreed with the eminent French chemist Chevreul that "to regard the distinction as absolute and invariable would be contrary to the spirit of science." If the laws of nature were the thoughts of God, then God would vouchsafe these thoughts to man if only he worked tirelessly to find them. Back in his mind was the suspicion that vital force was another one of those cryptic phrases, a creed which if accepted would destroy the progress of chemistry. Like the Chinaman who returned his first watch with the plaint that "it died last night," science had endowed those chemical compounds of living matter with the hidden, moving springs of vitalism.

Slowly, carefully, laboriously, Woehler worked away in the sacred temple of his laboratory. If he could only make one of those innumerable substances which until now only the intricate chemical workshop of the living organism had fashioned! What a blow he could strike at this false idea—a blow even more powerful than that which immortal Lavoisier had dealt to the mischievous theory of phlogiston half a century before him! As he dreamed and hoped he kept working, watching his test tubes and flasks, his evaporating dishes and condensers.

Friedrich Woehler had read the recently published work of Chevreul who had shown that many of the fats and other substances occurring in both the animal and vegetable kingdoms were identical. The barrier between animal and vegetable mat-

ter had thus been broken down. He was familiar with the work on animal chemistry of Rouelle, magnetic teacher of Lavoisier. These men had taken the first steps.

Woehler's goal was alluring. Experiment after experiment gave negative results but he kept plodding away. Once, in Berzelius' own laboratory in Stockholm, he had made some "peculiar white crystalline substance" which he could not identify. Four years passed. Then one afternoon the miracle happened.

Picture the amazement of this young researcher gazing upon a product which he had made out of lifeless compounds in an inanimate flask. Here under his eyes was a single gram of long, white, needle-like, glistening crystals which Rouelle had first found half a century before in urine and which Fourcroy had later studied and named urea. This white salt had never before been produced outside the living organism.

It was not strange that Woehler recognized at once this crystalline urea. He had started his career in science as a student of medicine and while competing for a prize for the best essay on the waste products found in urine, had come across urea.

Woehler was excited. He was standing upon the threshold of a new era in chemistry, witnessing "the great tragedy of science, the slaying of a beautiful hypothesis by an ugly fact." He had synthesized the first organic compound outside the living body. The pregnant mind of young Woehler almost reeled at the thought of the virgin fields rich in mighty harvests which now awaited the creatures of the crucible. He kept his head. He carefully analyzed his product to verify its identity. He must assure himself that this historic crystal was the same as that formed under the influence of the so-called vital force.

When he was sure of his ground, he wrote to Berzelius,

"I must tell you that I can prepare urea without requiring a kidney of an animal, either man or dog." The Swede enthusiastically spread the news. The world of science was electrified. Chevreul hailed the achievement with joy. Woehler had actually synthesized urea out of inorganic compounds! What was to prevent others from building up the sugars, the proteins, perhaps even protoplasm, the colloidal basis of life itself? A feeble protest still sounded from the vitalists. Urea was perhaps midway between the organic and inorganic world. For to make urea one must use ammonia which originally was of organic origin. The vital force present in organic substances never disappeared and consequently was capable of giving rise to other organic bodies. So they argued. But even that whisper was soon lost in the great tumult of excitement. It was indeed a brilliant new day for chemistry.

Woehler published his modest memoir on the synthesis of urea in 1828 and a century later Professor Amé Pictet and Hans Vogel of the University of Geneva succeeded in synthesizing cane sugar. Starting with simple hydrogen and carbon dioxide, seventy-year-old Pictet could change them into wood-alcohol, then into formaldehyde which yields glucose, and finally sucrose or cane sugar. For fifty years scientists had worked on this momentous piece of research.

Sir James Colquhoun Irvine, Vice Chancellor of the University of St. Andrews, Scotland, had himself worked on this problem for twenty years. He had almost succeeded in synthesizing this sugar when he read the announcement of Pictet's discovery. Irvine was thrilled and spoke to his students: "Naturally I am keenly disappointed that this synthesis did not occur in our own laboratory, but since it did not I am glad that Pictet gets the credit." No begrudging the work of a fellow researcher. No jealousy. "It is a great achievement," he con-

tinued, "It is a milestone in organic and biological chemistry." Such is the essence of science—the spirit of comradeship and good will in the entrancing work of piercing nature's secrets.

What a century of research between Woehler's urea and Pictet's sucrose! Four hundred thousand compounds have been prepared in this branch of synthetic chemistry, while every year four thousand new ones are added. No wonder that when Gmelin was preparing his handbook of chemistry he pleaded for chemists to stop discovering to give him a chance to catch up with his work. Woehler, a modest man, would have been the last to claim for himself the distinction of being the forerunner of such tremendous achievements.

Friedrich Woehler was born at the opening of the nineteenth century near Frankfort-on-the-Main. His father, Auguste, a man well educated in philosophy and science, was Master of the Horse to the Crown Prince of Hesse Cassel who was feared for his violent, impetuous temper. One day during an inspection tour of his stables, something very trifling displeased the Prince who began to abuse his servant. Auguste listened to his vile tongue until the Prince attempted to add a beating to his tongue lashing. Woehler would not put up with such humiliation even at the hands of a royal personage. Seizing a stout riding whip, he struck back fiercely until his master lay bleeding on the ground. Then jumping upon the fleetest horse in the stables and accompanied by a groom who was to return the steed, Auguste fled from Cassel. The Elector, fearing ridicule, did not pursue him.

Thus it came about that Friedrich was born not in the house of his parents but in the home of his uncle, who was clergyman of the village of Eschersheim. He received his early education from his father, who interested him in nature and encouraged him in drawing and in his hobby of mineral collecting.

Friedrich carried on a brisk exchange of minerals with his boyhood friends, which he continued even in later life. On one occasion he met the old poet Goethe, who was examining specimens in the shop of a mineral dealer in Frankfort.

Soon this boy added chemistry to his list of hobbies. Through his father he met a friend who had a rich library and a private chemical laboratory where he obtained permission to work. He built voltaic piles out of zinc plates and some old Russian copper coins he had collected. The master of the German mint presented him with an old furnace in which, with the aid of his sister to blow the bellows, he would build a roaring fire. And while he experimented he burned his fingers with phosphorus, and on another occasion was almost killed when a flask containing poisonous chlorine cracked in his hands.

At Marburg University, where his father, too, had been a student, he started to study medicine and won a prize for his investigations on the passage of different waste materials into urine. He performed numerous ingenious experiments upon his dog and even upon himself in preparing for this essay. Some of these experiments were dangerous to his health. He had not avoided them, however, even as twenty years before him, Dr. John Richardson Young, at twenty-two, had given his life at Hagerstown, Maryland, while using himself as a human beaker and test tube to prove that gastric juice and not a mysterious vital spirit was the essential factor in digestion. But chemistry still fascinated him. He built a little laboratory in his private room and prepared cyanogen iodide for the first time. He brought it to his teacher, Professor Wurzer, who reproached him for wasting his time on chemical experiments when he should have been studying his medicine. The sensitive boy was hurt and thereafter never attended the professor's lectures.

Soon the fame of Leopold Gmelin attracted him to Heidel-

berg. Here he continued his studies, gained the degree of Doctor of Medicine, Surgery, and Midwifery, and made ready to start on his travels to visit the great hospitals of Europe in further preparation for the practice of medicine. But Gmelin had watched this lad work in the chemical laboratory. He had told young Friedrich it would be a waste of time to attend his own lectures. Laboratory work was more important. Gmelin had read with pride his student's paper on the discovery of cyanic acid. He did not, at the time, dream this would in a few years lead to urea, but Gmelin was going to save Woehler for the disciples of Hermes. He spoke to him of the alluring career of a chemist. It was not very difficult to persuade Woehler. Often he had been tempted to turn away from medicine. Gmelin mentioned Berzelius whose fame as chemist had spread throughout Europe. He aroused in Friedrich the hope that perhaps Berzelius would give him permission to work under him in Stockholm.

Woehler wrote to the Swede, and within a few weeks received this answer: "Anyone who has studied chemistry under the direction of Leopold Gmelin has very little to learn from me, but I cannot forego the pleasure of making your personal acquaintance. You can come whenever it is agreeable to you." Woehler was walking on air. He hurried to Gmelin to tell him the good news. He was to make a pilgrimage to the laboratory of Berzelius.

He started at once. When he reached the town of Lübeck on the Baltic, he learned that he would have to wait six weeks for a small sailing vessel that was to take him to Stockholm. He was too impatient to wait so long in idleness. Through a friend, with whom as a boy he had exchanged minerals, he gained access to a private laboratory where he set to work

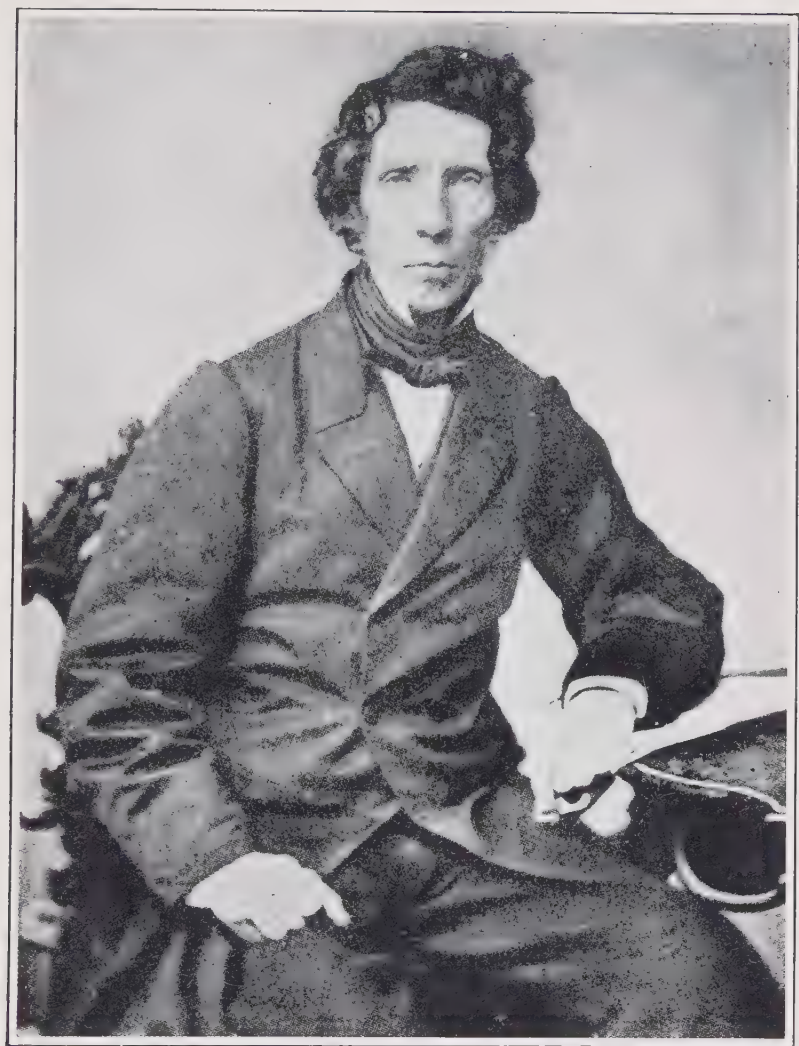
to find a method of making larger quantities of potassium, that violently active metal which Davy had just isolated.

At last he was on his way to Sweden. When he stepped off the boat the officer of the guard who examined his passport, on learning that he had come from Germany to study under Berzelius, declined to accept the usual fee. "I have too much respect for science and my illustrious countryman," he said, "to take money from one who in the pursuit of knowledge has undertaken so long a journey." Instead of the fee Woehler presented him with a piece of the wonderful potassium he had just prepared.

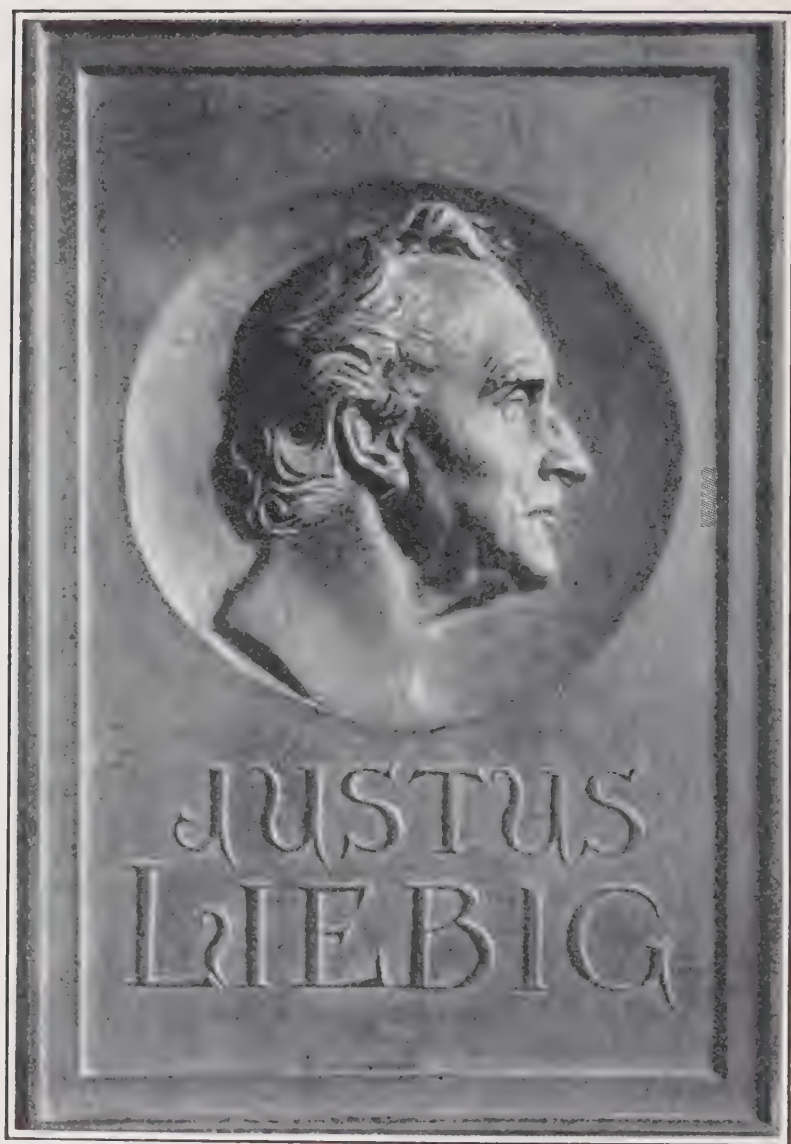
He reached Stockholm at night and nervously waited for the morning. "With a beating heart I stood before Berzelius' door and rang the bell. It was opened by a well-clad, portly, vigorous looking man. It was Berzelius himself. As he led me into his laboratory I was in a dream." Woehler never forgot his cordial reception by this master.

They wasted no time. Berzelius supplied the young student with a platinum crucible, a wash bottle, a balance and a set of weights, advised him to buy his own blowpipe, and set him to work on the examination of minerals. That was to be his first training in accurate analysis. When Woehler hurried to Berzelius to show him the result of his work his teacher warned him, "Doctor, that was quick but bad." Woehler remembered this valuable advice. Woehler now turned once more to his recently discovered cyanic acid and succeeded in preparing silver cyanate, a compound of this acid.

In the meantime, in the laboratory of Gay-Lussac in Paris worked another young German, Justus Liebig. This handsome, boisterous student, three years younger than Friedrich, was busy with the explosive fulminates. As a lad Liebig, whose father owned a small chemical factory, had seen an itinerant trades-



FRIEDRICH WOEHLE



JUSTUS LIEBIG

man making fireworks in his native city of Darmstadt. He was eager to learn the secrets of these explosive chemicals. During these researches Liebig prepared a strange compound. This substance was similar in composition to the silver cyanate of Woehler yet vastly different from it in both physical and chemical properties. Here was something very puzzling. How could two compounds made up of the identical elements in exactly the same proportions possess different properties? "Something must be wrong," said Liebig, and straightway he doubted Woehler's results. Perhaps he had misread his paper. He verified the results very carefully. Both Woehler and he were right in their conclusions.

Liebig communicated with his compatriot in Sweden. Woehler could not understand this strange phenomenon. He asked his master Berzelius to help him. The Swedish chemist recognized a tremendous discovery. *Isomers*—this was the term coined by Berzelius to designate chemical compounds having the same composition yet differing in properties—these had been discovered by two young men. This was only the beginning of similar findings in this new field. There were many substances which formed dozens of isomers. The phenomenon of isomerism in the chemistry of the carbon compounds helps to explain the tremendous number of different compounds of organic chemistry.

Later Liebig met Woehler at the latter's home. Woehler told Liebig of his excursion with his famous teacher through northern Norway and Sweden, during which he met Sir Humphrey Davy returning from a fishing trip. What an inspiration was the memory of that scene as he stood between Berzelius and Davy, the two foremost chemists of Europe.

At the time of their meeting, Liebig, though twenty-one, was professor of chemistry at the small University of Giessen. He

had received this appointment through the influence of Von Humboldt, the celebrated scientist, whom he had met in Gay-Lussac's laboratory in Paris. His salary amounted to only one hundred and twenty dollars a year plus about forty dollars for annual laboratory expenses. It was here that Liebig invented and developed a method of organic analysis still used to-day.

Woehler was teaching in the city trade school of Berlin and was spending a great deal of time translating into German some of the work of Berzelius from the Swedish, which he had learned while at Stockholm. Liebig admonished him to "throw away this writing to the devil and go back to the laboratory where you belong."

They discussed their mutual researches and their future plans for work to be performed in their respective laboratories. "Liebig expressed joyful assent at once and a research on mellitic acid was selected and carried to a successful conclusion." Fulminic acid was proposed as the next problem, but it was soon abandoned. "Fulminic acid we will allow to remain undisturbed," wrote Liebig. "I have vowed to have nothing to do with the stuff." For Liebig had almost lost his eyesight when some of it exploded under his nose and he was sent away to a hospital to ponder over its dangers. He also reminded Woehler how years before, while still a student at high school, it had exploded in the classroom, and he had been expelled with the verdict that he was "hopelessly useless."

Not that there could not be found men brave enough to wrestle with such obstreperous substances. Nicklés, a Swiss, lost his life in an attempt to isolate fluorine, an element more poisonous than chlorine. Louyet, too, had died of the effects of this gas while Knox, a Scotchman, ruined his health in its study. Dulong, before them, had lost an eye and three fingers while preparing nitrogen trichloride for the first time, and

continued to experiment with this compound even after the accident. On another occasion this same chemical knocked Faraday unconscious. The annals of chemistry contain many such examples of heroism.

In 1832 Woehler lost his young wife whom he had married two years before. It was a sudden shock that threatened to upset him permanently. He went to his friend Liebig for consolation and found it in his laboratory. During this year of bereavement the two young scientists published their joint paper on oil of bitter almonds. They studied a series of new compounds all containing an identical group of atoms which remained unchanged through the most diverse changes which their parent bodies underwent. To this unchanging group of atoms, consisting of carbon, hydrogen and oxygen, they gave the prosaic name of benzoyl. When Berzelius read of this work he saw in it the dawn of a new day in chemistry and suggested for this chemical group or radical the more poetic name of *proin*, the dawn. In Paris the chemical world talked a great deal of these researches.

Their work temporarily completed, Woehler returned to Cassel where he had been called the previous year. "I am back here again in my darkened solitude," he wrote to Liebig. "How happy was I that we could work together face to face. The days which I spend with you slip by like hours and I count them among my happiest."

For five years Woehler remained in Cassel. Here he met and married Julie Pfeiffer, a banker's daughter, by whom he had four daughters; one of them, Emilie, was to act as his secretary and biographer. His work in the field which he had opened had brought him fame. When Professor Strohmeyer, discoverer of the element cadmium, died, Woehler was selected from among a long list of candidates, including Liebig, to fill his

chair at the University of Göttingen, a position he held for almost half a century. Liebig never begrudged him this honor.

The two friends continued to work together and in 1838 they published the results of their experiments on uric acid, another organic compound. It was in this report that these pioneers foresaw the great future of organic chemistry. "The philosophy of chemistry," they wrote, "must draw the conclusion that the synthesis of all organic compounds must be looked upon not merely as probable but as certain of ultimate achievement. Sugar, salicin, morphine, will be artificially prepared." This was indeed prophetic.

The friendship of Woehler and Liebig stands out as a sublime example of scientific fraternity. Liebig spared no words in praise of his friend. "The achievement of our joint work upon uric acid and oil of bitter almonds was his work. Without envy and without jealousy, hand in hand we plodded our way; when the one needed help the other was ready. Some idea of this relationship will be obtained when I mention that many of our smaller pieces of work which bear our joint names were done by one alone; they were charming little gifts which one presented to the other." How different this from the too-frequent haggling of scientists over priority of discoveries!

Woehler was a great tonic for the hot-tempered Liebig who, as a student, had been forced to spend three days in jail for taking part in a gang fight. On this occasion he "made scurrilous remarks about those in authority and knocked the hat from the head of not only police officer Schramm but even of Councillor-in-Law Heim." More than once, when Liebig quarreled with a scientific contemporary who opposed his views, Woehler's calm advice smoothed things over. Liebig accused Elihard Mitscherlich, a student of Berzelius, of appropriating the apparatus of others and calling them his own.

Woehler pleaded with his friend to stop the quarrel. "Granted that you are perfectly in the right, that scientifically as well as personally you have cause to complain, by doing this you stoop from the elevated position in which posterity will see you to a vulgar sphere where the luster of your merits is sullied." Liebig made many enemies. His irascibility had estranged Berzelius whose friendship he valued very highly. He wrote to him wishing for permission to dedicate a book to him. Berzelius thanked him for this honor and incidentally criticized the style of the book. Liebig at once took offense, wrote him an insulting letter, and their friendship was forever at an end.

When Liebig got into trouble with Marchand, again Woehler stepped into the breach. "To contend with Marchand," he counselled, "will do you no good whatever or be of little use to science. It only makes you angry and hurts your liver. Imagine that it is the year 1900 when we are both dissolved into carbonic acid, water and ammonia, and our ashes, it may be, are part of the bones of some dog that has despoiled our graves. Who cares then whether we have lived in peace or anger; who thinks then of thy polemics, of thy sacrifice, of thy health and peace of mind for science? Nobody. But thy good ideas, the new facts which thou has discovered—these will be known and remembered to all time. But how comes it that I should advise the lion to eat sugar?"

Many of their vacations were spent travelling together. It was difficult to tear Liebig away from his laboratory. Woehler on one occasion tried to persuade him to join him on a trip through Italy. Woehler loved to take these excursions. He would carry his sketch book or easel with him, for he was a fair artist and the beauties of nature enthralled him. Liebig cared more for the smell of the laboratory and the adventures of chemical

discovery. "After all what good will it do me to have looked into the crater of Mt. Vesuvius?" he remarked.

In spite of Liebig's shortcomings, Woehler remained his friend to his death. Woehler knew his friend and made allowances for his fits of temper. "He who does not know him," said Woehler, "would hardly realize that at bottom he is one of the most good-natured and best fellows in the world."

Woehler, in his youth, had received an excellent education in the fine arts as well as in the sciences. He loved music, was encouraged in his attempts at oil painting by Christian Morgenstern, the landscape painter, and he made a more than superficial study of the German poets. Often his letters and parts of his lectures took on the nature of poetry. In one of his letters to Liebig from Italy we find, "On the highest summit of the Blue Mountain stands the palace of Tiberius, in whose shade I ate splendid grapes and figs while two brown-faced girls, the guides of our horses, danced the Tarantella to the sound of the tambourine."

Woehler built up a famous laboratory at Göttingen. It was among the first of the great teaching laboratories of the world. His fame as chemist and teacher spread over Europe. From every country students flocked to him and his laboratory became a veritable hive, busy day and night. From the United States came Professor James Curtis Booth, his first American student, and the late Professor Frank F. Jewett of Oberlin College, who brought back the story of his teacher's discovery and isolation of that extremely light, silvery metal, aluminum. Jewett was fond of talking to his classes of this strange metal which no one had as yet been able to obtain cheaply, in spite of its great abundance in the rocks of the earth. One day as he spoke of the fortune that awaited the man who would solve the problem of a simple method of aluminum extraction, one

of his students nudged the ribs of his young classmate, Charles Martin Hall. "I am going after that metal" said Hall, and on February 23, 1886 he handed Jewett a pellet of the shiny metal. Hall's process was patented that year. This was the beginning of the great Aluminum Company of America, producers of three hundred thousand tons of aluminum a year.

Woehler's kindly disposition endeared him to another young American student, the late Edgar Fahs Smith of the University of Pennsylvania. Woehler, black skull cap on his head, would sit for hours on a stool helping a beginner over some difficulty. The Geheimrat once noticed Smith emptying residues of his flasks in the drain outside the laboratory. "Recover your residues so that every thing of value will be saved," Woehler advised him, and together they outlined a method of recovery. When Smith had purified the residues, Woehler sent him to his friend, an apothecary, who bought them, thus saving the American his original expenses.

When Smith was ready for the final examinations for the degree of Doctor of Philosophy in Chemistry, he presented himself appropriately attired in dress suit and white gloves. Near the end of the examination Woehler, who was then old and somewhat feeble, straightened himself in his chair and asked his question. "Herr Candidate, will you tell me how you would separate the platinum metals from each other?" Smith acted somewhat confused, picked at the ends of his white gloves, and then, somewhat haltingly began to repeat the twelve pages of Woehler's treatise dealing with this subject. The Geheimrat, before the American had completed the answer, thanked him profusely and complimented him on his knowledge of the subject. The examination in chemistry was over. The next day, following the usual custom, Smith made a formal call on each of the professors. Woehler complimented him

again, saying that his answer at the examination was not only correct but expressed in perfect language. Then Smith confessed that the day before another candidate had tipped him off, and that he had memorized the twelve pages dealing with the separation of the platinum metals as found in his book on Mineral Analysis. "Woehler took it as a great joke and laughed heartily."

In the meantime organic chemistry was making prodigious strides. Marcellin Berthelot, master synthetic chemist of France, went to the ant and learned its secret. He prepared formic acid, the liquid which is responsible for the sting of the insect. Kolbe, crusading student of Woehler, prepared the acid of vinegar without the use of sweet cider or the mother-of-vinegar bacteria. William Perkin, washing bottles in the laboratory of Hofmann in London, mixed at random the contents of two flasks and discovered a method of synthesizing mauve—the first of a long series of coal-tar dyes which rival the colors of nature. Then Kekulé of Darmstadt, falling asleep in front of his fire in Ghent, dreamed of wriggling snakes, and woke up like a flash of lightning with the solution of a knotty problem. He had discovered the structure of benzene—parent substance of thousands of important compounds. Next, his pupil, Adolf von Baeyer, working for fifteen years on indigo, finally discovered its formula and made possible the manufacture of synthetic indigo fifteen years later by the Badische Company which had spent millions of dollars in research on this problem. This achievement rang the death knell of the prosperous indigo-growing industry of India, which soon went the way of its predecessor, the cultivation of woad. Had not Becher complained, "We give our gold to the Dutch for the trumpery color indigo and let the cultivation of woad in Thuringia go to perish."

Strangely enough, both Woehler and Liebig deserted this pregnant field of their original triumphs. Liebig turned to the chemistry of agriculture. In 1840 he tested his new theory of soil fertility on a barren piece of land near Giessen. The sceptics laughed but he kept feeding the soil with nothing but mineral fertilizers until he had turned it into as fertile a spot as could be found in all Germany. With one blow he had overturned the firmly rooted belief that plants can thrive only on manure or other organic matter in the soil. He had proved that the vegetable world could construct its organic material from the carbon dioxide and nitrogen of the air and the water of the ground. Others followed this pioneer work. Sir John Lawes at Rothamsted, England, started an experimental station which became the most famous of its kind in the world.

Yet Liebig was not happy in the change. "I feel," he wrote, "as though I were a deserter, a renegade who has forsaken his religion. I have left the highway of science and my endeavors to be of some use to physiology and agriculture are like rolling the stones of Sisyphus—it always falls back on my head, and I sometimes despair of being able to make the ground firm."

Woehler, too, had forsaken his first love almost in its infancy. "Organic chemistry nowadays almost drives me mad," he complained. "To me it appears like a primeval tropical forest full of the most remarkable things, a dreadful endless jungle into which one does not dare enter, for there seems no way out." He went to his minerals again and to the study of metals. In Sweden he had watched the master Berzelius at work on his researches of silicon, selenium and zirconium—three new elements. Woehler had learned much during his short stay and, a year before his immortal synthesis of urea, had already accomplished a research of the first order—the isola-

tion of the metal, aluminum, for the first time.¹¹ This same problem had defeated the genius of Davy. By treating a solid salt of aluminum with the intensely active potassium, Woehler was able to tear the metal away from its union and obtain it free as a white powder. But this sample of aluminum was only a laboratory curiosity—it cost a hundred and fifty dollars a pound.

Woehler's span of life covered the troubled days of the Napoleonic and Franco-Prussian Wars. As a lad he had seen the triumphal entry of the hated Napoleon into Frankfort. Sixty years later he heard of the capture of the French flags by the Prussians. Immediately, from Wiesbaden, where as a youth he had searched for urns and lamps in the ancient camps of the Romans, he wrote to Liebig, "The eagles of the captured French flags really consist of gilded aluminum, a metal that was first produced in Berlin in 1827. Such is fate." He modestly refrained from mentioning the part he played in the discovery of this metal.

Woehler isolated two other new elements, beryllium and yttrium, and because of illness which prevented an accurate analysis just missed discovering a fourth metal. This metal, vanadium, was soon isolated by N. G. Sefström. Woehler had sent a specimen of a lead ore containing this unknown metal to his friend Berzelius, and marked it with an interrogation point. Berzelius analyzed the mineral and replied with the following story: "In the remote regions of the north there dwells the Goddess Vanadis, beautiful and lovely. One day there was a knock at her door. The goddess was weary and thought she would wait to see if the knock would be repeated, but there was no repetition. The goddess ran to the window to look at the retreating figure. 'Ah,' she said to herself, 'it is that fellow Woehler.' A short time afterward there was another

knock, but this time so persistent and energetic that the goddess went herself to open it. It was Sefström, and thus it was that he discovered *vanadium*. Your specimen is, in fact, oxide of vanadium. But," continued Berzelius, "the chemist who has invented a way for the artificial production of an organic body can well afford to forego all claims to the discovery of a new metal, for it would be possible to discover ten unknown elements with the expenditure of so much genius."

The march of organic chemistry still went on after Woehler was dead. He lived long enough to see some of the miracles that succeeded the synthetic production of urea. But mightier developments followed. The story of this advance is like a tale from the Arabian Nights. Emil Fischer, refusing to enter the lumber business to please his father, turns to the chemical laboratory and builds up the most complex organic compounds, link to link and chain upon chain until he synthesizes sugars, polypeptides and other complex products like $C_{220}H_{142}O_{58}N_4I_2$, which resemble the natural peptones and albumins. No architect could work with greater precision. And when his father dies at the age of ninety-five, Fischer utters the regret "that he did not live to see his impractical son receive the Nobel Prize in Chemistry."

In another German laboratory, Paul Ehrlich jabs mice, rabbits and guinea pigs with injections of strange chemical compounds which he keeps changing and discarding by the dozens. He is searching for a differential poison—one which is more poisonous to the microorganism than to its host. Then one glorious morning, after six hundred and five trials, his synthetic drug—dihydroxy diamino arseno benzene dihydrochloride, that was its chemical name—kills the corkscrew trypanosomes, the deadly microbes that caused syphilis. Six-O-Six, this first

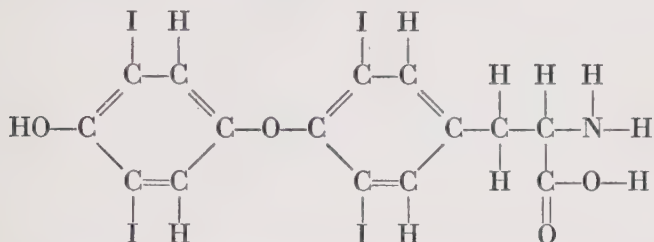
real specific against a virulent disease, was a product of synthetic chemistry.

A year later, in 1910, a slab of rubber and two rubber automobile tires were exhibited in New York by a German. The synthesis of rubber had been accomplished. But its production on a commercial scale, cheap enough to compete with natural rubber, is still a matter for the future. The seventy-five thousand dollar offer of the Russian Soviet Government for five pounds of commercial synthetic rubber, with its recipe delivered at Moscow before January 1, 1928, brought no claimants.

The list of achievements is still incomplete. Chemists have not feared to join battle with any product of the living organism. They have studied the active internal secretions of the ductless glands of the body. These secretions, called *hormones* (from the Greek—to arouse or excite), enter the blood stream in extremely minute amounts as catalyst, and control growth, intelligence and other functions of the nervous system. The first of these hormones to be synthesized (Stolz, 1906) was *epinephrine* (adrenalin), the active ingredient of two tiny, cocked hats found one on top of each kidney. The hormone of these suprarenal tissues was isolated as early as 1897 by Abel and Takamine, a Japanese scientist. It is the hormone of the hero and the coward. For the absence or overactivity of the suprarenal bodies has a tremendous influence on human action. During an emotional crisis the adrenals become very active and produce great strength. Their overactivity in the female accounts for the deep-voiced, bearded lady of the circus.

In 1915 Dr. Edward C. Kendall of the Mayo Foundation isolated the hormone of the thyroid gland, *thyroxine*. This needle shaped crystal containing 65% iodine is found to the extent of less than a quarter of a grain in the whole body, and

influences the rate of oxidation in the body. When the thyroid is overactive it produces either a symmetrical giant or a gorilla type of man. When underdeveloped, it results in a misshapen dwarf of the intelligence of an idiot. Two years ago Dr. C. R. Harington of England succeeded in synthesizing this important hormone from coal-tar products. It was a prodigious task. Its formula according to Harington is:



Its name, beta - tetra - iodo - hydroxy - phenoxy - phenyl - alpha-amino-propionic acid, may soon be a blessing to mankind.

The isolation and purification of insulin, the active principle of the Islets of Langerhans (a collection of cells in the pancreas) by Dr. F. G. Banting, C. H. Best and Professor Macleod of the University of Toronto, has proven a boon to diabetics. The work of analyzing this life-saving hormone to determine its structure is still incomplete. Chemists are also experimenting with synthetic products similar to chaulmoogra oil, used in the Orient to cure the vilest of all diseases—leprosy. Drugs and medicines like procaine, butyn, psicaine, tutocaine, aspirin, phenacetin, urotropin, and veronal (barbital) have been synthesized to alleviate the pains of mankind. The essential oils of the synthetic chemist rival the odors of Arabia and Persia, while his colors outshine the rainbow.

The mind fairly reels at the thought of the possibilities of this new branch of chemistry. Chemistry, once the handmaid, is now the mistress of medicine, for life is largely a matter of

chemistry. Our bodies are organic chemical factories. Chemical experiments are to-day controlling the growth of cells, the unit of life, outside the living body. On January 17, 1912, Dr. Alexis Carrel, a Nobel Prize winner in medicine, took several minute fragments from the heart of a chick embryo and cultivated them. "The bits of tissue went on pulsating and surrounded themselves with connective tissue cells." But in a few days this ceased and "degeneration was imminent." Then Carrel, by carefully regulating the chemical composition of the medium in which the cells were placed, was able to get the heart tissue pulsating again, and "to-day many experiments are made with the pure strain descended from the tiny fragment of pulsating tissue" that he possessed in 1912. He has succeeded in keeping alive minute portions of the original strain for more than fifteen years.

Here we are on the very rim of life. Wonders succeed wonders. Carrel found that a colony of cells, originally a pinhead in volume, would produce in twenty days a mass of tissue equal to a gram. After sixty days the volume of living tissue would be as large as a cubic yard. Tissues growing at this rate for sixteen years would reach a volume greater than that of the entire solar system, millions of miles in diameter. This would be staggering, but many factors prevent this unlimited proliferation. "Although the body is composed of elements which are potentially immortal," says Carrel, "it is and will always be subject to senility and death. In spite of the fact that the higher animals will never reach immortality, there is some hope that the duration of life may be artificially increased. *The solution of this problem rests on the future progress of cell physiology and the chemistry of nutrition.*"

The belief in the old vital force which Woehler destroyed is still dead, but in its place there remains another vital power

more puzzling than ever. Warburg in Germany, A. V. Hill in England and L. Henderson and Van Slyke in America are working to unravel the mysterious force which controls the birth, growth and development of living forms. Eugenio Rignano, an Italian philosopher, has hopes that this biotic or vitalistic nervous energy will some day be discovered. Sir Oliver Lodge recently told an audience at Oxford University that "it is sometimes said by students of organic chemistry that if we could contrive in the laboratory to continue the manufacture of organic compounds until we had a mass of protoplasm, and were able to subject it to suitable pressure, they would expect that artificial protoplasm to exhibit vitality and manifest one or another form of life." While this is no challenge to the conception of God, as some fundamentalists maintain, yet it is difficult to believe that man will ever be able to produce that entelechy or expanding vital impulse which can breathe the breath of life into the most complex chemical compound he makes. Man is more than a chemical concatenation of a lump of coal, a whiff of air and a beaker of water. The phenomenon of life is more than a chemical reaction and a physical change. Beyond the chemist's widest synthetic horizon lies some mysterious life force.

And the achievement of even this tremendous task would not frighten the philosopher Emerson. For to him, scientific triumph was not the death but the birth of further mystery. "I do not know that I should feel threatened or insulted if a chemist should take this protoplasm or mix his hydrogen, oxygen and carbon, and make an animacule incontestably swimming and jumping before my eyes. I should only feel that it indicated that the day had arrived when the human race might be trusted with a new degree of power and its immense responsibility; for these steps are not solitary or local, but only a

hint of an advanced frontier suggested by an advancing race behind it.”

Woehler died in his eighty-third year, following an illness of only three days. After a simple funeral he was buried in Göttingen, the city of his life work. In accordance with his wish only a modest legend was carved on his tombstone—Friedrich Woehler; Born July 31, 1800; Died Sept. 23, 1882. At Downs, five months before, there passed away another pioneer of science, Charles Darwin, the man who recreated life out of the rocks and fossils of the earth even as Woehler created a new world of compounds out of the same inanimate stones, and with them showed the way to the modern Elixirs of Life.

XI

MENDELÉEFF

SIBERIA BREEDS A PROPHET

OUT of Russia came the patriarchal voice of a prophet of chemistry. "There is an element as yet undiscovered. I have named it eka-aluminum. By properties similar to those of the metal aluminum you shall identify it. Seek it, and it will be found." Startling as was this prophecy, the sage of Russia was not through. He predicted another element resembling the element boron. He was even bold enough to state its atomic weight. And before that voice was stilled, it foretold the discovery of a third element whose physical and chemical properties were thoroughly described. No man, not even the Russian himself, had beheld these unknown substances.

This was the year 1869. The age of miracles was long past. Yet here was a distinguished scientist, holding a chair of chemistry at a famous university, covering himself with the mantle of the prophets of old. Had he gathered this information from inside the crystal glass of some sorcerer? Perhaps, like the seer of ancient times, he had gone to the top of a mountain to bring down the tablets of these new elements. But this oracle disdained the robes of a priest. Rather did he announce his predictions from the stillness of his chemical laboratory, where midst the smoke, not of a burning bush, but of the fire of his furnace, he had seen visions of a great generalization in chemistry.

Chemistry had already been the object of prophecy. When Lavoisier heated some tin in a sealed flask and found it to

change in appearance and weight, he saw clearly a new truth, and foretold other changes. Lockyer a year before had looked through a new instrument—the spectroscope devised by Bunsen and Kirchhof. Through this spectroscope he had gazed at the bright colored lines of a new element ninety-three million miles away. Since it was present in the photosphere of the sun he called it *helium* and predicted its existence on our earth. Twenty-one years later, William Hillebrand of the United States Geological Survey, came across this gas in the rare mineral cleveite.

But the predictions of the Russian were more astounding. He had made no direct experiments. He had come to his conclusions seemingly out of thin air. There had gradually been born in the fertile mind of this man the germ of a great truth. It was a fantastic seed but it germinated with surprising rapidity. When the flower was mature, he ventured to startle the world with its beauty.

In 1884 Sir William Ramsay had come to London to attend a dinner given in honor of William Perkin, the discoverer of the dye mauve. "I was very early at the dinner," Ramsay recalled, "and was putting off time looking at the names of people to be present, when a peculiar foreigner, every hair of whose head acted in independence of every other, came up bowing. I said, 'We are to have a good attendance, I think?' He said, 'I do not spik English.' I said, 'Vielleicht sprechen sie Deutsch?' He replied, 'Ja ein wenig. Ich bin Mendeléeff.' Well, we had twenty minutes or so before anyone else turned up and we talked our mutual subject fairly out. He is a nice sort of fellow but his German is not perfect. He said he was raised in East Siberia and knew no Russian until he was seventeen years old. I suppose he is a Kalmuck or one of those outlandish creatures."

This "outlandish creature" was Mendeléeff, the Russian prophet to whom the world listened. Men went in search of the missing elements he described. In the bowels of the earth, in the flue dust of factories, in the waters of the oceans, and in every conceivable corner they hunted. Summers and winters rolled by while Mendeléeff kept preaching the truth of his visions. Then, in 1875, the first of the new elements he foretold was discovered. In a zinc ore mined in the Pyrenees, Lecoq de Boisbaudran came upon the hidden eka-aluminum. This Frenchman analyzed and reanalyzed the mineral and studied the new element in every possible way to make sure there was no error. Mendeléeff must indeed be a prophet! For here was a metal exactly similar to his eka-aluminum. It yielded its secret of two new lines to the spectroscope, it was easily fusible, it could form alums, its chloride was volatile. Every one of these characteristics had been accurately foretold by the Russian. Lecoq named it *gallium* after the ancient name of his native country.

But there were many who disbelieved. "This is one of those strange guesses which by the law of averages must come true," they argued. Silly to believe that new elements could be predicted with such accuracy! One might as well predict the birth of a new star in the heavens. Had not Lavoisier, the father of chemistry, declared that "all that can be said upon the nature and number of the elements is confined to discussions entirely of a metaphysical nature? The subject only furnishes us with indefinite problems."

But then came the news that Winkler, in Germany, had stumbled over another new element, which matched the eka-silicon of Mendeléeff. The German had followed the clue of the Russian. He was looking for a dirty gray element with an atomic weight of about 72, a density of 5.5, an element which was slightly acted upon by acids. From the silver ore, argyro-

dite, he isolated a grayish white substance with atomic weight of 72.3 and a density of 5.5. He heated it in air and found its oxide to be exactly as heavy as had been predicted. He synthesized its ethide and found it to boil at exactly the temperature that Mendeléeff had prefigured. There was not a scintilla of doubt about the fulfilment of Mendeléeff's second prophecy. The spectroscope added unequivocal testimony. Winkler announced the new element under the name of *germanium* in honor of his fatherland. The sceptics were dumbfounded. Perhaps after all the Russian was no charlatan!

Two years later the world was completely convinced. Out of Scandinavia came the report that Nilson had isolated eka-boron. Picking up the scent of the missing element in the ore of euxenite, Nilson had tracked it down until the naked element, exhibiting every property foreshadowed for it, lay before him in his evaporating dish. The data were conclusive. The whole world of science came knocking at the door of the Russian in St. Petersburg.

Dmitri Ivanovitch Mendeléeff came of a family of heroic pioneers. More than a century before his birth, Peter the Great had started to westernize Russia. Upon a marsh of pestilence he reared a mighty city which was to be Russia's window to the West. For three-quarters of a century Russia's intellectual march eastward continued, until in 1787 in Tobolsk, Siberia, the grandfather of Dmitri opened up the first printing press, and with the spirit of a pioneer published the first newspaper in Siberia, the *Irtysch*. In this desolate spot, settled two centuries before by the Cossacks, Dmitri was born on February 7, 1834. He was the last of a family of seventeen children.

Misfortune overtook his family. His father, director of the local high school, became blind, and soon after died of consumption. His mother, Maria Korniloff, a Tartar beauty, unable

to support her large family on a pension of five hundred dollars a year, reopened a glass factory which her family was the first to establish in Siberia. Tobolsk at this time was an administrative center to which Russian political exiles were taken. From one of these prisoners of the revolt of 1825, a "Decembrist" who married his sister, Dmitri learned the rudiments of natural science. When fire destroyed the glass factory, little Dmitri, pet of his aged mother—she was already fifty-seven—was taken to Moscow in the hope that he might be admitted to the University. Official red tape prevented this. Determined that her son should receive a good scientific education, his mother undertook to move to St. Petersburg, where he finally gained admittance to the Science Department of the Pedagogical Institute, a school for the training of high school teachers. Here he specialized in mathematics, physics and chemistry. The classics were distasteful to this blue-eyed boy. Years later, when he took a hand in the solution of Russia's educational problems, he wrote, "We could live at the present time without a Plato, but a double number of Newtons is required to discover the secrets of nature, and to bring life into harmony with its laws."

Mendeléeff worked diligently at his studies and graduated at the head of his class. Never very robust during these early years, his health gradually weakened, and the news of his mother's death completely unnerved him. He had come to her as she lay on her death bed. She spoke to him of his future: "Refrain from illusions, insist on work and not on words. Patiently search divine and scientific truth." Mendeléeff never forgot those words. Even as he dreamed, he always felt the solid earth beneath his feet.

His physician gave him six months to live. To regain his health, he was ordered to seek a warmer climate. He went to the south of Russia and obtained a position as science master

at Simferopol in the Crimea. When the Crimean War broke out he left for Odessa, and at the age of twenty-two he was back in St. Petersburg as a privat-docent. An appointment as privat-docent meant nothing more than permission to teach, and brought no stipend save a part of the fees paid by the students who attended the lectures. Within a few years he asked and was granted permission from the Minister of Public Instruction to study in France and Germany. There was no opportunity in Russia for advanced work in science. At Paris he worked in the laboratory of Henri Regnault and, for another year, at Heidelberg in a small private laboratory built out of his meager means. Here he met Bunsen and Kirchhof from whom he learned the use of the spectroscope, and together with Kopp attended the Congress of Karlsruhe, listening to the great battle over the molecules of Avogadro. Cannizzarro's atomic weights were to do valiant service for him in the years to come. Mendeléeff's attendance at this historic meeting ended his *Wanderjahre*.

The next few years were very busy ones. He married, completed in sixty days a five-hundred page textbook on organic chemistry which earned him the Domidoff Prize, and gained his doctorate in chemistry for a thesis on *The Union of Alcohol with Water*. The versatility of this gifted teacher, chemical philosopher and accurate experimenter was soon recognized by the University of St. Petersburg, which appointed him full professor before he was thirty-two.

Then came the epoch-making year of 1869. Mendeléeff had spent twenty years reading, studying and experimenting with the chemical elements. All these years he had been busy collecting a mass of data from every conceivable source. He had arranged and rearranged this data in the hope of unfolding a secret. It was a painstaking task. Thousands of scientists had

worked on the elements in hundreds of laboratories scattered over the civilized world. Sometimes he had to spend days searching for missing data to complete his tables. The number of the elements had increased since the ancient artisans fashioned instruments from their gold, silver, copper, iron, mercury, lead, tin, sulphur and carbon. The alchemists had added six new elements in their futile search for the seed of gold and the elixir of life. Basil Valentine, a German physician, in the year when Columbus was discovering America had rather fancifully described antimony. In 1530 Georgius Agricola, another German, talked about bismuth in his *De Re Metallica*, a book on mining which was translated into English for the first time by President and Mrs. Hoover in 1912. Paracelsus was the first to mention the metal zinc to the Western World. Brandt discovered glowing phosphorus in urine, and arsenic and cobalt were soon added to the list of the elements.

Before the end of the eighteenth century, fourteen more elements were discovered. In far away Choco, Colombia, a Spanish naval officer, Don Antonio de Ulloa, had picked up a heavy nugget while on an astronomical mission, and had almost discarded it as worthless before the valuable properties of the metal platinum were recognized. This was in 1735. Then came lustrous nickel, inflammable hydrogen, inactive nitrogen, life-giving oxygen, death-dealing chlorine, manganese, used for burglar-proof safes, tungsten, for incandescent lamps, chromium, for stainless steel, molybdenum and titanium, so useful in steel alloys, tellurium, zirconium, and uranium, heaviest of all the elements. The nineteenth century had hardly opened when Hatchett, an Englishman, discovered columbium (niobium) in a black mineral that had found its way from the Connecticut Valley to the British Museum. And thus the search went on, until in 1869 sixty-three different elements had been

isolated and described in the chemical journals of England, France, Germany and Sweden.

Mendeléeff gathered together all the data on these sixty-three chemical elements. He did not miss a single one. He even included fluorine whose presence was known, but which had not yet been isolated because of its tremendous activity. Here was a list of all the chemical elements, every one of them consisting of different Daltonian atoms. Their atomic weights, ranging from 1 (hydrogen) to 238 (uranium), were all dissimilar. Some, like oxygen, hydrogen, chlorine and nitrogen, were gases. Others, like mercury and bromine, were liquids under normal conditions. The rest were solids. There were some very hard metals like platinum and iridium, and soft metals like sodium and potassium. Lithium was a metal so light that it could float on water. Osmium, on the other hand, was twenty-two and a half times as heavy as water. Here was mercury, a metal which was not a solid at all, but a liquid. Copper was red, gold yellow, iodine steel gray, phosphorus white, and bromine red. Some metals, like nickel and chromium, could take a very high polish; others like lead and aluminum, were duller. Gold, on exposure to the air, never tarnished, iron rusted very easily, iodine sublimed and changed into a vapor. Some elements united with one atom of oxygen, others with two, three or four atoms. A few, like potassium and fluorine, were so active that it was dangerous to handle them with the unprotected fingers. Others could remain unchanged for ages. What a maze of varying, dissimilar, physical characteristics and chemical properties!

Could some order be found in this body of diverse atoms? Was there any connection between these elements? Could some system of evolution or development be traced among them, such as Darwin, ten years before, had found among the multiform varieties of organic life? Mendeléeff wondered. The problem

haunted his dreams. Constantly his mind reverted to this puzzling question.

Mendeléeff was a dreamer and a philosopher. He was going to find the key to this heterogeneous collection of data. Perhaps nature had a simple secret to unfold. And while he believed it to be "the glory of God to conceal a thing," he was firmly convinced that it was "the honor of kings to search it out." And what a boon it would prove to his students!

He arranged all the elements in the order of increasing atomic weights, starting with the lightest, hydrogen, and completing his table with uranium, the heaviest. He saw no particular value in arranging the elements in this way; it had been done previously. Unknown to Mendeléeff, an Englishman, John Newlands, had three years previously read, before the English Chemical Society at Burlington House, a paper on the arrangement of the elements. Newlands had noticed that each succeeding eighth element in his list showed properties similar to the first element. This seemed strange. He compared the table of the elements to the keyboard of a piano with its eighty-eight notes divided into periods or octaves of eight. "The members of the same group of elements," he said, "stand to each other in the same relation as the extremities of one or more *octaves* in music." The members of the learned society of London laughed at his Law of Octaves. Professor Foster ironically inquired if he had ever examined the elements according to their initial letters. No wonder—think of comparing the chemical elements to the keyboard of a piano! One might as well compare the sizzling of sodium as it skims over water to the music of the heavenly spheres. "Too fantastic," they agreed, and J. A. R. Newlands almost went down to oblivion.

Mendeléeff was clear-visioned enough not to fall into such a pit. He took sixty-three cards and placed on them the names

and properties of the elements. These cards he pinned on the walls of his laboratory. Then he carefully reexamined the data. He sorted out the similar elements and pinned their cards together again on the walls. A striking relationship was thus made clear.

Mendeléeff now arranged the elements into seven groups, starting with lithium (at. wt. 7), and followed by beryllium (at. wt. 9), boron (11), carbon (12), nitrogen (14), oxygen (16) and fluorine (19). The next element in the order of increasing atomic weight was sodium (23). This element resembled lithium very closely in both physical and chemical properties. He therefore placed it below lithium in his table. After placing five more elements he came to chlorine, which had properties very similar to fluorine, under which it miraculously fell in his list. In this way he continued to arrange the remainder of the elements. When his list was completed he noticed a most remarkable order. How beautifully the elements fitted into their places! The very active metals lithium, sodium, potassium, rubidium and caesium fell into one group (No. 1). The extremely active non-metals, fluorine, chlorine, bromine and iodine, all appeared in the seventh group.

Mendeléeff had discovered that the properties of the elements "were periodic functions of their atomic weights," that is, their properties repeated themselves periodically after each seven elements. What a simple law he had discovered! But here was another astonishing fact. All the elements in Group I united with oxygen two atoms to one. All the atoms of the second group united with oxygen atom for atom. The elements in Group III joined with oxygen two atoms to three. Similar uniformities prevailed in the remaining groups of elements. What in the realm of nature could be more simple? To know the properties of one element of a certain group was to know, in a

general way, the properties of all the elements in that group. What a saving of time and effort for his chemistry students!

Could his table be nothing but a strange coincidence? Mendeléeff wondered. He studied the properties of even the rarest of the elements. He re-searched the chemical literature lest he had, in the ardor of his work, misplaced an element to fit in with his beautiful edifice. Yes, here was a mistake! He had misplaced iodine, whose atomic weight was recorded as 127, and tellurium, 128, to agree with his scheme of things. Mendeléeff looked at his Periodic Table of the Elements and saw that it was good. With the courage of a prophet he made bold to say that the atomic weight of tellurium was wrong; that it must be between 123 and 126 and not 128, as its discoverer had determined. Here was downright heresy, but Dmitri was not afraid to buck the established order of things. For the present, he placed the element tellurium in its proper position, but with its false atomic weight. Years later his action was upheld, for further chemical discoveries proved his position of tellurium to be correct. This was one of the most magnificent prognostications in chemical history.

Perhaps Mendeléeff's table was now free from flaws. Again he examined it, and once more he detected an apparent contradiction. Here was gold with the accepted atomic weight of 196.2 placed in a space which rightfully belonged to platinum, whose established atomic weight was 196.7. The fault-finders got busy. They pointed out this discrepancy with scorn. Mendeléeff made brave enough to claim that the figures of the analysts, and not his table, were inaccurate. He told them to wait. He would be vindicated. And again the balance of the chemist came to the aid of the philosopher, for the then-accepted weights were wrong and Mendeléeff was again right.

Gold had an atomic weight greater than platinum. This table of the queer Russian was almost uncanny in its accuracy!

Mendeléeff was still to strike his greatest bolt. Here were places in his table which were vacant. Were they always to remain empty or had the efforts of man failed as yet to uncover some missing elements which belonged in these spaces? A less intrepid person would have shrunk from the conclusion that this Russian drew. Not this Tartar, who would not cut his hair even to please his Majesty, Czar Alexander III. He was convinced of the truth of his great generalization, and did not fear the blind, chemical sceptics.

Here in Group III was a gap between calcium and titanium. Since it occurred under boron, the missing element must resemble boron. This was his eka-boron which he predicted. There was another gap in the same group under aluminum. This element must resemble aluminum, so he called it eka-aluminum. And finally he found another vacant space between arsenic and eka-aluminum, which appeared in the fourth group. Since its position was below the element silicon, he called it eka-silicon. Thus he predicted three undiscovered elements and left it to his chemical contemporaries to verify his prophecies. Not such remarkable guesses after all—at least not to the genius Mendeléeff!

In 1869 Mendeléeff, before the Russian Chemical Society, presented his paper *On the Relation of the Properties to the Atomic Weights of the Elements*. In a vivid style he told them of his epoch-making conclusions. The whole scientific world was overwhelmed. His great discovery, however, had not sprung forth overnight full grown. The germ of this important law had begun to develop years before. Mendeléeff admitted that “the law was the direct outcome of the stock of generalizations of established facts which had accumulated by the end of the

decade 1860-1870." De Chancourtois in France, Strecher in Germany, Newlands in England, and Cooke in America had noticed similarities among the properties of certain elements. But no better example could be cited of how two men, working independently in different countries, can arrive at the same generalization, than the case of Lothar Meyer, who conceived the Periodic Law at almost the same time as Mendeléeff. In 1870 there appeared in *Liebig's Annalen* a table of the elements by Lothar Meyer which was almost identical with that of the Russian. The time was ripe for this great law. Some wanted the boldness or the genius necessary "to place the whole question at such a height that its reflection on the facts could be clearly seen." This was the statement of Mendeléeff himself. Enough elements had been discovered and studied to make possible the arrangement of a table such as Mendeléeff had prepared. Had Dmitri been born a generation before, he could never, in 1840, have enunciated the Periodic Law.

"The Periodic Law has given to chemistry that prophetic power long regarded as the peculiar dignity of the sister science, astronomy." So wrote the American scientist Bolton. Mendeléeff had made places for more than sixty-three elements in his Table. Three more he had predicted. What of the other missing building blocks of the universe? Twenty-five years after the publication of Mendeléeff's Table, two Englishmen, following a clue of Cavendish, came upon a new group of elements of which even the Russian had never dreamed. These elements constituted a queer company—the Zero Group as it was later named. Its members, seven in number, are the most unsociable of all the elements. Even with that ideal mixer, potassium, they will not unite. Fluorine, most violent of all the non-metals cannot shake these hermit elements out of their inertness. Moissan tried sparking them with fluorine but failed to make them com-

bine. Besides, they are all gases, invisible and odorless. Small wonder they had remained so long hidden.

True, the first of these noble gases, as they were called, had been observed in the sun's chromosphere during a solar eclipse in August, 1868, but as nothing was known about it except its orange yellow spectral line, Mendeléeff did not even include it in his table. Later, Hillebrand described a gas expelled from cleveite. He knew enough about it to state that it differed from nitrogen but failed to detect its real nature. Then Ramsay, obtaining a sample of the same mineral, bottled the gas expelled from it in a vacuum tube, sparked it and detected the spectral line of helium. The following year Kayser announced the presence of this gas in very minute amounts, one part in 185,000, in the earth's atmosphere.

The story of the discovery and isolation of these gases from the air is one of the most amazing examples of precise and painstaking researches in the whole history of science. Ramsay had been casually introduced to chemistry while convalescing from an injury received in a football game. He had picked up a textbook in chemistry and turned to the description of the manufacture of gunpowder. This was his first lesson in chemistry. Rayleigh, his co-worker, had been urged to enter either the ministry or politics, and when he claimed that he owed a duty to science, was told his action was a lapse from the straight and narrow path. Such were the initiations of these two Englishmen into the science which brought them undying fame. They worked with gases so small in volume that it is difficult to understand how they could have studied them. Rayleigh, in 1894, wrote to Lady Frances Balfour: "The new gas has been leading me a life. I had only about a quarter of a thimbleful. I now have a more decent quantity but it has cost about a thousand times its weight in gold. It has not yet been christened.

One pundit suggested 'aeron,' but when I have tried the effect privately, the answer has usually been, 'When may we expect Moses?' " It was finally christened argon, and if not Moses, there came other close relatives: neon, krypton, xenon and finally niton. These gases were isolated by Ramsay and Travers from one hundred and twenty tons of air which had been liquefied. Sir William Ramsay used a micro-balance which could detect a difference in weight of one fourteen-trillionth of an ounce. He worked with a millionth of a gram of invisible, gaseous niton—the size of a tenth of a pin's head.

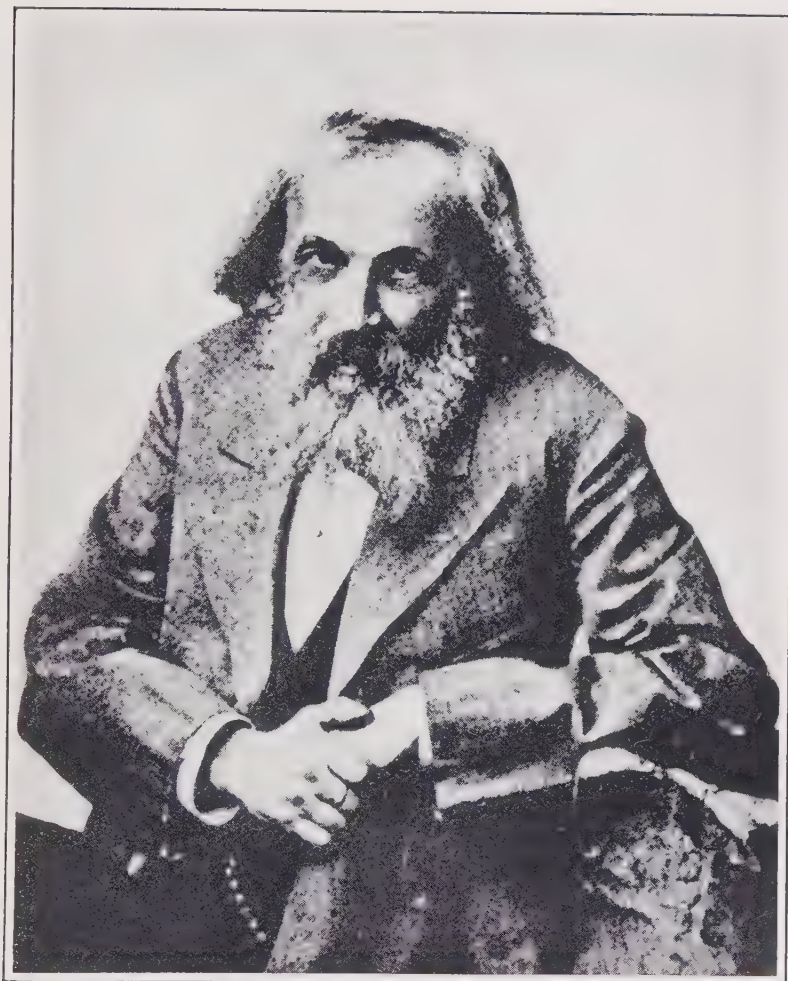
Besides these six Zero elements, some of which are doing effective work in argon and neon incandescent lamps, in helium-filled dirigibles, in electric signs, and in replacing the nitrogen in compressed air to prevent the "bends" among caisson workers, seventeen other elements were unearthed. So that, a year after Mendeléeff died in 1907, eighty-six elements were listed in the Periodic Table, a fourfold increase since the days of Lavoisier.

Mendeléeff, besides being a natural philosopher in the widest sense of the term, was also a social reformer. He understood the brutality and tyranny of beaurocratic Russia. He had learned his first lessons from the persecuted exiles in frozen Tobolsk. As he travelled about Russia, he went third class, and engaged in intimate conversation with the peasants and small tradespeople in the trains. They hated the remorseless oppression and espionage of the government. Mendeléeff was not blind to the abuses of Russian officialdom, nor did he fear to point them out. He was often vehement in his denunciations. This was a dangerous procedure in those days. But the government needed Mendeléeff, and his radical utterances were always tinged with due respect for law and order. He was neither a revolutionist nor a republican. At heart he was a royalist. The

pomp and splendor of Russian royalty did not displease him. But he clamored for reforms. On more than one occasion when this scientific genius showed signs of political eruption, he was hastily sent away on some government mission. Far from the centers of unrest he was much safer and of greater value to the officials.

In 1876, Mendeléeff was commissioned by the government of Alexander II to visit the oil fields of Pennsylvania in distant America. These were the early days of the petroleum industry. In 1859, Colonel Edwin L. Drake and his partner "Uncle Billy" Smith had gone to Titusville, Pennsylvania, to drive a well sixty-nine feet deep—the first to produce oil on a commercial scale. Mendeléeff had already been of invaluable service to Russia by investigating and throwing open her extensive oil fields of Baku in the Caucasus. Here, from a gap in the rock, burned the "everlasting flame" which Marco Polo had described centuries back. Baku was the most prolific single oil district in the world and, from earliest times, people had burned its oil which they had dipped from its springs. Mendeléeff developed an ingenious theory to explain the origin of these oil deposits. He refused to accept the prevalent idea that oil was the result of the decomposition of organic material in the earth, and postulated that energy-bearing petroleum was formed by the interaction of water and metallic carbides found in the interior of the earth.

On his return from America, Mendeléeff was again sent to study the naphtha springs in the south of Russia. He did not confine his work to the gathering of statistics and the enunciation of theories. He developed in his own laboratory a new method for the commercial distillation of these products and saved Russia vast sums of money. He studied the coal region on the banks and basin of the Donetz River and opened it to



DMITRI IVANOVITCH MENDELÉEFF

the world. He was an active propagandist for Russia's industrial development and expansion, and was called upon to help frame a protective tariff for his country.

This was a period of intense social and political unrest in Russia. Alexander II had attempted to settle the land question of his twenty-three million serfs. He tried further to ameliorate conditions by reforming the judicial system, relaxing the censorship of the press, and developing educational facilities. The young students in the universities presented a petition for a change in certain educational practices. Suddenly an insurrection against the Russian government broke out in Poland. The reactionary forces again gained control. Russia was in no mood for radical changes; the requests of the students were peremptorily turned down. Mendeléeff stepped in and presented another of their petitions to the officials of the government. He was bluntly told to go back to his laboratory and stop meddling in the affairs of the state. Proud and sensitive, Mendeléeff was insulted and resigned from the University. Prince Kropotkin, a Russian anarchist of royal blood, was one of his famous students. "I am not afraid," Mendeléeff had declared, "of the admission of foreign, even of socialistic ideas into Russia, because I have faith in the Russian people who have already got rid of the Tartar domination and the feudal system." He did not change his views even after the Czar, in 1881, was horribly mangled by a bomb thrown into his carriage.

Mendeléeff had made many enemies by his espousal of liberal movements. In 1880, the St. Petersburg Academy of Sciences refused, in spite of very strong recommendations, to elect him member of its chemical section. His liberal tendencies were an abomination. But other and greater honors came to this sage. The University of Moscow promptly made him one of its honorary members. The Royal Society of England presented

him with the Davy Medal which he shared with Lothar Meyer for the Periodic Classification of the Elements.

Years later, as he was being honored by the English Chemical Society with the coveted Faraday Medal, Mendeléeff was handed a small silk purse worked in the Russian national colors and containing the honorarium, according to the custom of the Society. Dramatically he tumbled the sovereigns out on the table, declaring that nothing would induce him to accept money from a Society which had paid him the high compliment of inviting him to do honor to the memory of Faraday in a place made sacred by his labors. He was showered with decorations by the chemical societies of Germany and America, by the Universities of Princeton, Cambridge, Oxford, and Göttingen. Sergius Witte, Minister of Finance under Czar Alexander III, appointed him Director of the Bureau of Weights and Measures.

Mendeléeff broke away from the conventional attitude of Russians towards women, and treated them as equals in their struggle for work and education. While he held them to be mentally inferior to men, he did not hesitate to employ women in his office, and admitted them to his lectures at the university. He was twice married. With his first wife, who bore him two children, he led an unhappy life. She could not understand the occasional fits of temper of this queer intellect. The couple soon separated and were eventually divorced. Then he fell madly in love with a young Cossack beauty of artistic temperament, and, at forty-seven, remarried. Anna Ivanovna Popova understood his sensitive nature, and they lived very happily. She would make allowances for his flights of fancy and occasional selfishness. Extremely temperamental and touchy, he wanted everybody to think well of him. At heart he was kind and lovable. Two sons and two daughters were born to them and Mendeléeff oftentimes expressed the feeling that "of all things

I love nothing more in life than to have my children around me." Dressed in the loose garments which his idol, Leo Tolstoy, wore, and which Anna had sewed for him, Dmitri would sit at home for hours smoking. He made an impressive figure. His deep-set blue eyes shone out of a fine expressive face half covered by a long patriarchal beard. He always fascinated his many guests with his deep guttural utterances. He loved books, especially books of adventure. Fenimore Cooper and Byron thrilled him. The theatre did not attract him, but he loved good music and painting. Accompanied by his wife, who herself had made pen pictures of some of the great figures of science, he often visited the picture galleries. His own study was adorned by her sketches of Lavoisier, Newton, Galileo, Faraday, and Dumas.

When the Russo-Japanese War broke out in February, 1904, Mendeléeff turned out to be a strict monarchist. Old as he was, he added his strength in the hope of victory. Made advisor to the Navy, he invented pyrocollodion, a new type of smokeless powder. The destruction of the Russian fleet in the Straits of Tsushima and Russia's defeat hastened his end. His lungs had always bothered him; as a youth his doctor had given him only a few months to live. But his powerfully-set frame carried him through more than seventy years of life. Then one day in February, 1907, the old scientist caught cold, pneumonia set in, and as he sat listening to the reading of Verne's *Journey to the North Pole*, he expired. Two days later Menshutkin, Russia's eminent analytical chemist, died, and within one year Russia lost also her greatest organic chemist, Friedrich Konrad Beilstein. Staggering blows to Russian chemistry.

To the end, Mendeléeff clung to scientific speculations. He published an attempt towards a chemical conception of the ether. He tried to solve the mystery of this intangible something

which pervades the whole universe. To him ether was material, belonged to the Zero Group of Elements, and consisted of particles a million times smaller than the atoms of hydrogen.

Two years after he was laid beside the grave of his mother and son, Pattison Muir declared that "the future will decide whether the Periodic Law is the long looked for goal, or only a stage in the journey: a resting place while material is gathered for the next advance." Had Mendeléeff lived a few more years, he would have witnessed the complete and final development of his Periodic Table by a young Englishman at Manchester.

The Russian peasant of his day never heard of the Periodic Law, but he remembered Dmitri Mendeléeff for another reason. One day, to photograph a solar eclipse, he shot into the air in a balloon, "flew on a bubble and pierced the sky."

XII

ARRHENIUS

THREE MUSKETEERS FIGHT FOR IONS

IN THE historic chemical laboratory of the University of Leipzig two men, a German born in Riga, and a Swede, met towards the end of the nineteenth century to plan a great battle against an established theory and the scientific inertia which upheld it. Meanwhile, over in Amsterdam, another scientist, a Dutchman, worked in the same campaign. From this triumvirate came a barrage of scientific experiments which made possible a new era in the field of theoretical and applied chemistry. Here, at Leipzig, the Headquarters of the Ionians, the great struggle was directed.

The three were all young men. Svante Arrhenius was hardly more than a boy. Van't Hoff, the Dutch professor, was thirty-five, and Ostwald, the moving spirit of the revolt, a year younger. The quest for scientific truth had brought these three together, and they vowed to force the venerable authorities of the scientific world to accept the new leaven of the younger generation. The masters, under whom they had cut their scientific eye-teeth, must be shown the folly of ignoring genius among their students.

One of the most difficult problems of that time was a rational understanding of what goes on in a solution when an electric current is sent through it. Even before that memorable day, nearly a century before, when the first experimenter arranged the two poles of his galvanic battery so that an electric current might pass through a solution, this problem had puzzled and

perplexed the brainiest of those who followed him. Both Davy and Grothuss had attempted explanations. Faraday, discoverer of electromagnetic induction, had also investigated this subject and had created its terminology. Yet no solution had been found.

The same love of adventure that impelled his countryman Rolf to set sail for the coasts of Normandy prompted Svante Arrhenius to undertake the exploration of a problem that had baffled men grown old in dingy laboratories. An electric current could not be made to traverse distilled water. Neither would solid salt offer free passage to electricity. Yet when salt and water were mixed, their solution became a liquid through which electricity could pass with ease. And, as the electric current passed through this solution, a deep-seated decomposition took place. How could one explain this strange behavior of solutions?

Svante not only wondered but set to work. He was a visionary who soared in the clouds as he watched his test tubes and beakers. He had always been a dreamer, even when as a lad he attended school in his native village of Wijk near Upsala. At seventeen he had graduated, the youngest and ablest student of his class. He had given a brilliant account of himself in mathematics and the sciences. Carried on the shoulders of his friends, he was taken to the nearest hat shop to obtain the white velvet cap—insignia of the university student. At the State University of Upsala, where his father, too, had studied, he chose chemistry as his major subject. He hoped to follow in the footsteps of Berzelius, who, eighty years before, had walked the same halls and listened to the romance of chemistry in the same lecture rooms.

At twenty-two, Svante was ready for his doctorate and went to Stockholm. He had some queer notions of his own about the



SVANTE ARRHENIUS

passage of electricity through solutions. He had done a great deal of thinking and experimenting along this line. Why not choose this problem for his thesis? It did not take him long to decide. He shut himself up in his laboratory. Day after day and often far into the night he filled beaker after beaker with solutions of different salts. One shining glass beaker contained a weak solution of copper sulphate. He labelled it accurately. A second tumbler was filled with a still weaker solution of magnesium sulphate. All over his laboratory table were bottles and flasks neatly marked with formulas and concentrations. Through each of these solutions he passed electric currents. He weighed, measured and recorded all of the results. And, as he watched bubbles of gas issuing from the plates dipped into the various solutions, his hunch, which was to solve the mystery, grew stronger.

Cavendish, a century before, had attempted to compare quantitatively the electrical conductivity of rain-water with various salt solutions. Possessing no galvanometer to register the strength of the currents, he had bravely converted his own nervous system into one. As he discharged Leyden jars through the different liquids he compared the electric shocks which he received. With this crude, heroic method he obtained a number of surprisingly accurate results.

Arrhenius was much better equipped. Great strides had since been made in the field of electrical measurements. He, too, was an accurate worker and a patient one. For two years he toiled ceaselessly. Tiring, monotonous work, you might say. What joy or fun in sticking shiny electrodes into dozens of glass beakers and watching bubbles of gas or the movements of the dials on galvanometers, ammeters and voltmeters? The sun never shone for Svante during those months in the laboratory. He tried in-

numerable experiments with more than fifty different salts in all possible degrees of dilution.

"My great luck was that I investigated the conductivities of the most dilute solutions," he wrote later. "In these dilute solutions the laws are simple compared with those for concentrated solutions, which had been examined before." Luck it was, to some extent. But others had observed how the passage of the electric current became easier as more water was added to the concentrated solutions. They, too, had noticed some relation between the strength of an acid and its power to conduct a current. Arrhenius, however, was the first to see clearly the strange relationship between the ease of passage of an electric current through a solution, and the concentration of that solution.

Midst the never-ending washing of beakers and bottles and the perpetual weighings and recordings, Arrhenius stole moments to ponder over the meaning of it all. But first he must finish all of the experimental work. In the spring he had completed it. "I have experimented enough," he said. "Now I must think." He left his laboratory and returned to his home in the country to work out the theoretical part of his research. One night he sat up till very late. In those days the whole world, both of his waking and sleeping existence, was a world of solutions, currents and mathematical data. The rest did not exist. From the sublimated speculations of his experiments, suddenly there crystallized like a flash the answer to the great riddle. "I got the idea in the night of the 17th of May in the year 1883, and I could not sleep that night until I had worked through the whole problem."

Svante had a keen pictorial faculty and a remarkable memory which helped him visualize the whole range of data he had collected during those two years at Upsala. As a boy he would

sit beside his father, manager of the University grounds, and help him with the accounts of the estate. He could remember and repeat with ease long rows of figures.

His thesis was now completed. He returned to Upsala with the dissertation in his pocket. He came to Clève, his professor of chemistry, with the new theory formulated in his thesis. "I have a new theory of electrical conductivity," said Svante Arrhenius. Clève, discoverer of holmium and thulium, was no doubt a skilful experimenter and investigator of the rare earth elements. But theories to him were abominations to be fought or ignored entirely. In the classroom Arrhenius had listened to him for months. Never once had he heard a single mention of the great Periodic Law of Mendeléeff, even though the Russian's Table of the Elements was now more than ten years old.

Clève turned to this chemical tyro. "You have a new theory? That is very interesting. Good-by." Svante did not lose heart. He knew Clève—he had not expected a very enthusiastic response.

As a candidate for the doctor's degree, Arrhenius had to defend his thesis in open debate. This was an event of great interest. The University appointed an opponent. Svante had taken special care in preparing his thesis. His professors at Upsala would be sure to search for the slightest error even of type-setting. He recognized the impossibility of getting them to accept the whole of his heterodox theory. He must not offend existing beliefs too ruthlessly. As a candidate for the doctorate he could not afford to tear down the idols they worshiped and hope to escape damnation. He could not, without danger to the theory he had conceived, make the heretical statements to which his thinking had led him. To save his new theory he was willing to compromise a little. "If I had made such statements in my

doctor's thesis it would not have been approved," he later told the scientific world.

Arrhenius feared the enthusiasm of his youth might overstep the bounds of safety. He held himself in check. Carefully he chose the words for his answers. He made sure not to ride roughshod over the established principles of the University of Upsala.

At the end of four hours the questioning was over. Svante, in formal dress, waited breathlessly for the verdict. He expected trouble. The professors appeared to look upon him as a "stupid school-boy" as Arrhenius remarked years later. They examined his complete record at the University. He had done fairly good work in mathematics, physics and biology.

The final result was announced. In spite of his dissertation, he was grudgingly awarded his degree, and as a laurel wreath was placed on his head, a cannon outside boomed the advent of another doctor of philosophy. The award, however, was in reality a veiled condemnation of his theory. His dissertation was awarded a fourth class and his defence a third class.

Svante was almost broken-hearted. "It was difficult to see how the University of Upsala, the University of Bergman and Berzelius, could have condemned a brilliant thesis on the very subject of electrochemistry associated with their names." This was the judgment of Sir James Walker, professor of chemistry at the University of Edinburgh. This discouragement might have ended Svante's career as a chemist. But he was convinced that he had within his thesis a tool which would be a blessing to science. He, the Viking of Truth, was ready to do battle to vindicate his theory. But first he must ally himself with men of power in the field of chemistry. He himself was an unknown—he might look ludicrous in the armor of a chemical crusader.

Upsala was not friendly; he was certain of that. Stockholm, too, was unenthusiastic—had he not submitted his thesis to the



VAN'T HOFF and OSTWALD
Working on Ionization

Swedish Academy of Sciences only to be met with a cold reception? Sweden, the country of Scheele, Berzelius, and Linnaeus, could not see the prophet within its walls.

Svante decided to appeal to the scientific world outside of Sweden. He sent a copy of his thesis to Rudolf Clausius, formulator of the Second Law of Thermodynamics. This German scientist was also the recognized oracle of electrochemistry. More than thirty years before, he had said: "In a solution the atoms composing molecules are constantly exchanging partners and, as a consequence, a certain proportion of the atoms will be uncombined at any instant." This statement seemed then the last word on the subject of Arrhenius' dissertation. "He was a great authority," thought Arrhenius, "therefore it could not be regarded as unwise to share his ideas," at least in part. Arrhenius, therefore, explained that the molecules which are active in solution "*are in the state described by Clausius.*" This expression "did not look so dangerous." But his tactful attempt to win over this German authority also failed. He received no encouragement. Clausius, now old and in feeble health, was not sufficiently interested.

Oliver Lodge also received a copy of his thesis. Lodge was, perhaps, the foremost scientist of England at the time. This was before he had abandoned pure science to grapple with the hidden mysteries of spiritualism. He had not as yet embarked upon his adventures of photographing fairies and trapping the ectoplasm of departing souls. Still deeply rooted in the soil of scientific experimentation, he recognized in Arrhenius' paper "a distinct step towards a mathematical theory of chemistry." But that was all the active encouragement he gave the young Swedish scientist.

Arrhenius now sent his dissertation to Lothar Meyer. Surely Meyer would have the vision to see and the courage to uphold

this new theory! For had he not, independently of Mendeléeff, arrived at the Periodic Law of the Elements? Had not he, Lothar Meyer, back in 1860 at Karlsruhe, listened to the vehement voice of Cannizzaro, and had he not at once championed the great truth of that Italian crusader? Surely this German would enter the lists in support of his heterodox theory! But Lothar Meyer, too, was silent.

Wilhelm Ostwald, professor of chemistry at the Polytechnical School at Riga, also heard from Arrhenius. This champion of daring chemical causes received Svante's paper on the day his wife presented him with a new daughter. He was suffering, that very day, from a painful toothache! Ostwald later remarked that it "was too much for one day. The worst was the dissertation, for the others developed quite normally."

Arrhenius somehow felt that Ostwald would understand. That was a lucky hunch. Ostwald read every word of that memoir. He was tremendously excited. He flew up like a hornet and raged at the stupidity of the Upsala professors. One could not help recognizing the genius of this young man. He jumped at the revolutionary idea that only *ions* took part in chemical reactions. Here was another momentous cause worth fighting for.

Ostwald lost no time. Dropping all his work, he left at once for Sweden. He made the long journey from Riga to Stockholm convinced that assistance had to come immediately to the young talent. The two met in Stockholm in August, 1884.

What was this iconoclastic doctrine of young Svante, which kindled a blaze and set the chemical world afire? Arrhenius introduced a startling idea. He said that when a solid salt like common table salt, sodium chloride, was dissolved in water a tremendous change took place. This change was invisible. Pure water itself was a non-conductor of electricity. The pure solid salt, likewise, would not conduct an electric current. But when

salt and water were mixed, an instantaneous change occurred. The molecules of sodium chloride split up, *dissociated* or *ionized* into particles which, years before, Faraday had labelled *ions* at the suggestion of William Whewell, an expert in nomenclature. Faraday had pictured these *ions* as being produced by the electric current. Arrhenius said they were already present in the solution, even before the electric current was sent through.

These two parts of the molecule of sodium chloride were absolutely *free*. In solution the ions swam around in all directions. There were no longer any sodium chloride molecules present. Only sodium ions and chlorine ions peopled the water. Here was the crash of a holy idol. Clausius had said that only *some* of the molecules were in this peculiar condition of dismemberment. Young Svante, the beginner, had dared declare that *all* the molecules in dilute solutions were disrupted.

If this were true, some asked, then why could not the greenish yellow color of poisonous chlorine be seen? It was a logical and formidable question. Arrhenius answered that the chlorine *ions* differed from the *atoms* of chlorine because the ions were electrically charged. Dissociation had changed the atoms into ions, and the charge of electricity had changed the ion to such an extent that it differed fundamentally from its parent atom.

Arrhenius represented the change as follows:



Here was a new chemistry—the chemistry of *ions*—strange, infinitesimal particles of matter bearing infinitely small electric charges which carried an electric current through solutions, and then, as they touched the electrodes, gave up their electric charges and returned once more to the atomic state. This mighty drama took place every time an inorganic acid, alkali or salt

dissolved in water. Arrhenius was the first who saw clearly this invisible miracle rôle of the molecule in solution.

Ostwald grasped the value of this explanation almost at a glance. He was ready to accept the sweeping statement that chemical reactions in solution were reactions between *ions*. What a vast new field of experimentation it opened to science!

Ostwald and Arrhenius spent many pleasant days together in Stockholm. As they walked arm in arm along the shores of beautiful Lake Malar they spoke about ions until they were as real and tangible as so many electrified balls. "Ostwald of course visited my dear friend and teacher Clève," wrote Arrhenius. "Ostwald spoke to him one day in his laboratory. I came a little later; I was not expected. I heard Clève say: 'Do you *believe* sodium chloride is dissolved into sodium and chlorine? In this glass I have a solution of sodium chloride. Do you believe there are sodium and chlorine in it? Do they look so?' 'Oh, yes,' Ostwald said, 'there is some truth in that idea.' Then I came in and the discussion was at an end. Clève threw a look at Ostwald which clearly showed that he did not think much of his knowledge of chemistry." But Ostwald would not hurt the old professor. Besides, he was saving his powder for the great battle ahead. "We made plans," wrote Arrhenius, "regarding the development of the whole of chemistry."

Ostwald had been completely won over by the blond, rufous, blue-eyed Swede. He invited him to come to Riga to continue his investigations in his laboratory. Svante might have gone on the moment. He was weary of the stubbornness of the professors of Upsala and Stockholm. But just then death came to his father, and he was delayed. Later, through the influence of Ostwald, he was given a travelling scholarship and at the close of 1885 his five years of *Wanderjahre* began. He went straight to Riga to work under the inspiration of Ostwald. There

were many dubious points to be settled. They wanted to be absolutely certain. They needed reams of experimental ammunition to meet the terrific onslaught of the sceptical world of science. Ostwald, in the meantime, was working on the conductivity of acids.

The winter of 1886-7 was approaching. Arrhenius had spent almost a year with Ostwald. Friedrich Kohlrausch at Wurtzburg had been busy experimenting on the conductivity of solutions and had discovered that all the ions of the same element, regardless of the compound from which they were formed, behaved in exactly the same way. Arrhenius heard of his valiant work in this new field, and determined to leave Ostwald for a while and study with Kohlrausch. Surely he could learn something from this skillful German. At Wurtzburg, too, Arrhenius was to meet Emil Fischer. This young Jew, walking in the footsteps of Woehler, was busy with the synthesis of complex organic compounds. Arrhenius stopped to talk to him about his ions. Fischer was fascinated by the new conception, but he warned the Swede that most chemists would not readily accept his theory. It was too visionary, too revolutionary.

Arrhenius must present a fool-proof theory or be damned by the chemical world as the parent of a monstrosity. In Kohlrausch's laboratory he jumped into the work again with the fervor of a fanatic. He must bring to the unbelieving world of science inexorable facts and invulnerable data. He read voraciously every piece of research that touched upon his subject. His star was bound to rise; soon he came across a memoir by Jacobus Hendrik van't Hoff.

Van't Hoff was a dreamer with a mind that leaped above the commonplace facts of chemistry and dared postulate new ideas. At twenty-two he had founded a new branch of chemistry, "stereochemistry," or the chemistry of atoms in space. He,

too, had met with stubborn opposition. The world was up in arms against the "space chemistry" of this upstart. Kolbe, a distinguished German chemist, likened his stereochemistry to the belief in witchcraft. It was pernicious and dangerous. He raved against this fledgeling. "A certain Dr. van't Hoff, an official of the Veterinary School at Utrecht," Kolbe wrote, "has no taste for exact chemical investigations. He has thought it more convenient to bestride Pegasus, evidently hired at the veterinary stables, and to proclaim in his *Chemistry in Space* how, during his bold flight to the top of the chemical Parnassus, the atoms appeared to him to have grouped themselves throughout universal space." Van't Hoff was not perturbed. He photographed the most decrepit horse to be found in the veterinary stables, labeled it Pegasus, and hung it on the walls of the University of Utrecht.

Van't Hoff had fought his way to recognition, championed by the same Wilhelm Ostwald. His "distorted theory" grew into a robust idea which did much to develop the field of organic chemistry. Now van't Hoff, thirteen years older, wrote about a theory of solution which suggested that dissolved substances obeyed the same laws as gases. Arrhenius read the paper very carefully. In it he found experimental data which was to help him fashion his own theories into a wonderfully consistent whole. He recognized in the Dutchman's memoir a great argument for his own theory of ionization.

Arrhenius was eager to work with van't Hoff. Time was passing rapidly and there was still much to be done. It was now the summer of 1887. But first he must meet Ludwig Boltzmann at Gratz with whom he worked until the following spring. Then Arrhenius set out for Amsterdam. On his way he stopped at Kiel to talk with Professor Max Planck, who became keenly interested in his theory and spent some time investigating it.

This man Planck was another visionary who at the opening of the twentieth century, was to enunciate the "quantum" principle, a law of nature that shook the whole scientific world.

The friendship of Arrhenius and van't Hoff began when they met for the first time in Amsterdam. As van't Hoff worked side by side with Arrhenius for months, their devotion grew. Few men worked with more unselfishness. They talked about each other's theories. They discussed solutions, ions, gas laws and osmotic pressure. They pledged themselves to do battle for a common cause.

But Arrhenius was beginning to miss the fire of Ostwald, the human dynamo, whose essential characteristic was energy. He was almost ready for his final memoir on the chemical theory of electrolytes. He needed the effective aid and the cheering encouragement of his commander. Ostwald had written telling him of his new appointment as professor at the University of Leipzig. Arrhenius went there immediately. In the presence of Ostwald he could not help but gain renewed confidence in his theory. They brought together all the puzzling facts of electrolysis of solutions. Here they sat and planned the great Battle of the Ions. Ostwald had the foresight and shrewdness of the modern campaigner. He was ready to launch a drive that was to end in a wave of enthusiasm for the ideas of Arrhenius. He first used the weapon of his newly founded scientific journal—the *Zeitschrift für Physikalische Chemie*—to broadcast the new theory of dissociation. He knew that the great notoriety which would be given to the theory even by opposition would suffice to launch a tremendous amount not only of discussion but of experimentation.

Ostwald's campaign was effective. Europe began to hear about Arrhenius and his strange ions. The young students in Ostwald's laboratory had been the first to hear the odd name

of Svante Arrhenius. In the halls outside the laboratory where they gathered to smoke—they were forbidden this luxury in the laboratory—they spoke in whispers about this man whom their master had taken under his wing. Sir James Walker recalled how one day he “peered out of the laboratory and saw a stoutish, fair young man talking to Ostwald near the entrance hall. It was Arrhenius. We were made acquainted by Ostwald. He was the simplest and least assuming of men. He gave himself no airs.”

When, in 1887, Arrhenius’ classical paper “On the Dissociation of Substances in Aqueous Solutions” appeared in the first volume of the *Zeitschrift*, there was printed beside it van’t Hoff’s memoir on the analogy between the gaseous and dissolved state. As was anticipated, great opposition was aroused. The Battle of the Ions was raging in earnest. Ostwald led his small but valiant army of Ionians like a true warrior of old. His two solitary lieutenants were Arrhenius and van’t Hoff. The host of the opposition was a formidable one. There were many in the workshops of science who would not swallow these ions. Even Mendeléeff opposed them, because he did not consider the theory in accordance with facts. His opposition, however, was not so severe. He believed that “the conception of electrical dissociation, although retarding the progress of the theory of solutions, was useful in giving the motive for collecting a store of experimental data to be embraced by a truer explanation in the future.” Others, more severe, brought argument after argument to bear against these ions.

Ostwald, the great chemical crusader, leader of forlorn and victorious hopes, was impatient. “Let us attack them,” he boomed, “that is the best method.” He opened the pages of his chemical journal to the champions of the great cause. He invaded the enemy’s territory. He worked heroically in his own

laboratory. He instituted the first laboratory for instruction in physical chemistry in history. Students came to him from all over the world. From England came Ramsay. From America came Harry Clary Jones of Johns Hopkins, Wilder Bancroft of Cornell, Arthur Amos Noyes and William David Coolidge of the Massachusetts Institute of Technology, and the late Theodore W. Richards of Harvard. Ostwald had difficulty in speaking English; he filled his mouth with zwiebach to get the correct sound of "the." His students were amazed at his energy and enthusiasm. The young Americans, especially, looked up to him with reverence, for he had been the sole chemist in all Europe who, more than ten years before, had recognized the work of the modest retiring American, Josiah Willard Gibbs of Yale, one of the greatest scientific products of his generation.

In 1890, the three musketeers of physical chemistry met in England, where they were invited to discuss the theory of solution with a committee of the British Association. Opinion was now divided as to the merits of the new theory. Many frankly admitted they were not competent to pass judgment. Professor Percival Pickering maintained that "the theory of dissociation is altogether unintelligible to the majority of chemists." They wanted to ask more questions of these wild Ionians. Ramsay, who had studied under Ostwald, tried to clear the way for the acceptance by English scientists of the views of Arrhenius. Lodge, too, was present, and was not antagonistic to the new theory. But Lord Kelvin of Glasgow was not convinced. Sir William Tilden also was hostile, nor would the French chemists accept the theory of Ionization. It was a bitter uphill battle. Ostwald, Arrhenius and van't Hoff parted with renewed declarations to see the fight through.

Ostwald wrote to Arrhenius to come and settle down in Leipzig as a professor at the University, but he chose to stay

in Sweden, and accepted a minor position as lecturer and teacher at the Technical High School of Stockholm. Here he remained for four years and found time, between his ion-chasing and bottle washing, to marry Sofia, the daughter of Lieutenant-Colonel Carl Rudback. A son was born to them, Olav Vilhelm, who to-day may be found in the ranks of the workers on soil science and agricultural botany.

His post at the Technical High School was now to be converted into a professorship at the University of Stockholm. The news of this impending change spread. The enemies of the Ionians gathered to prevent the appointment of Arrhenius. He could not be ousted without some semblance of trial. It was agreed to subject him to an examination. What humiliation! Arrhenius, laughing inwardly at this farce, presented himself before the trio of learned scientists. Lord Kelvin, the eminent British scientist, was one of the examining committee. Dr. Hasselberg, a Swede, and Christiansen, a Dane, completed the group of inquisitors.

Far away at Leipzig Ostwald heard of this and roared, "It is preposterous to question the scientific standing of such a giant as Arrhenius." He wrote to Stockholm and fought hard for his friend. The examination, however, came off as scheduled. Arrhenius, not at all disconcerted, answered the volleys of questions quietly and confidently. This time he was not going to distort the truth of ionization even for a Kelvin.

When the examination was over and the report submitted, a new tumult was raised. Kelvin opposed the theory in general. He could understand nothing, he said, which could not be translated into a mechanical model. For this reason he had likewise rejected Maxwell's electromagnetic theory of light. Only the Dane submitted an enthusiastic judgment of the competence of Arrhenius. His own countryman, Hasselberg, de-

clared that his answers "were not physical enough" to make him fitted for a professorship. What a comedy! The University authorities kept searching, in the meantime, for a foreign professor to fill the newly created position. Had they succeeded in obtaining one eminent enough to accept the chair of chemistry, they would have side-tracked Arrhenius altogether. But Ostwald kept fighting tooth and nail for his friend. The University of Stockholm feared a scientific scandal. And just as the Bunsen Society in Germany was electing him an honorary member for his Theory of Dissociation, Arrhenius was finally made professor at the University of Stockholm.

The struggle for recognition was still going on. The theory had opponents a-plenty. Professor H. E. Armstrong of England likened it to phlogiston. From Oswald's own laboratory, at Leipzig, Louis Kahlenberg had graduated with a Ph.D., *summa cum laude*, the highest honor attainable. He had dug into the theory of Arrhenius but was not convinced of its truth. The theory had entirely neglected the existence of chemical reactions in solutions other than water. Arrhenius had declared that chemical reactions took place only between *ions* in solution. But Kahlenberg had undeniable proof that some reactions took place in solutions which could not conduct an electric current and hence, according to Arrhenius, contained no ions. And here was another objection. Silver nitrate dissolved in benzonitrile allowed the electric current to traverse it, yet this solution contained no ions. Curious exceptions to the theory of Arrhenius.

Kahlenberg went back to the University of Wisconsin and worked ten years as professor of chemistry to disprove the truth of the conception of Arrhenius. He tried the queerest experiments, which seemed miles away from his subject. But Wisconsin was a place for freak experiments, anyway. Here Stephen Moulton Babcock and his young assistants performed the most

outlandish experiments on men and beasts and finally discovered the "hidden hunger" of the vitamins. For weeks Kahlenberg gathered together an experimental group of fifteen people in his office. There were twelve young men between the ages of twenty and thirty, three young women of the same ages, one woman of sixty, and a man of sixty-three. He had them taste all sorts of beverages and carefully record their reactions. When he finally disbanded this council of taste he had come to the conclusion that here, at least, Arrhenius was right. *Hydrogen ions* were responsible for the sour taste of acids. A strong acid was one which contained a large number of these hydrogen ions, and a weak acid contained only a few of these ions.

But what of the numerous cases which would not fit into Arrhenius' scheme of things? Kahlenberg was just as emphatic in opposing the ionic theory as his teacher Ostwald was in defending it. "The difficulties," Kahlenberg declared, "which the theory of electrolytic dissociation encounters are really insurmountable." He challenged the Ionians to "try to recall any real marked improvements or discoveries in the realm of electrolysis which are directly traceable to the influence of the dissociation theory. These polemical discussions," he asserted, "are doing considerable good in that they emphasize how inadequate the dissociation theory really is; they represent the beginning of the end of that theory." To Kahlenberg the theory was but a web of naked fancies.

As late as 1900 Kahlenberg fought against the theory and prophesied its doom. But he lives to-day, and has witnessed the triumph of Ionization.¹² "The chemistry of atoms and molecules gave place to the chemistry of ions," declared Jones. Ostwald used the completed theory of Arrhenius with such skill and understanding that he laid the basis of a new analytical chemistry upon the bedrock of ions. Electrolysis, electro-

plating and other applications of electrochemistry have their foundations deeply rooted in this new theory. Even physiology and bacteriology have come to it for support.

The authorities had made no mistake in promoting Arrhenius. Within two years after his appointment as professor, he was elected President of the University. His great battle was being won. His fame began to spread. Five years later the Royal Society of England honored him with the Davy Medal. In the following year came the crowning recognition. He received the Nobel Prize, the highest honor in science.

In June, 1904, he spoke before the Royal Institution, and the following week sailed for America, on his first visit to the United States. At the St. Louis Exposition to which he had been invited, he again saw Ostwald and van't Hoff. The three musketeers were still riding. They met again to take stock of the new theory. It had fared well. Two of the musketeers were Nobel Prize winners, and Ostwald was soon to be similarly honored.

On the way home Arrhenius was offered a professorship of chemistry at the Berlin Academy of Sciences, the same honor which van't Hoff had previously accepted. King Oscar II of Sweden planned a more tempting offer to keep him at home. The King founded the Nobel Institute for Physical Research at Stockholm, and Arrhenius was made director. Oxford and Cambridge honored him with degrees.

On the twenty-fifth anniversary of the appearance of Arrhenius' thesis, Ostwald dedicated a whole volume of his *Zeitschrift* to it. Bancroft of Cornell, LeBlanc of Leipzig, Le Chatelier of Paris, Ciamiciau of Bologna, Van Deventer of Amsterdam, H. C. Jones of Johns Hopkins, Wegscheider of Vienna, and other distinguished scientists filled the pages of

that journal and crowded out many who begged to be allowed to contribute. The battle had been won with glory.

In 1911 Arrhenius again visited this country to deliver a series of lectures at our principal universities. He spoke at Johns Hopkins, Yale, Ohio State University, the College of the City of New York and Columbia. He was invited by the Chemists' Club of New York to talk to its members on May 17, because on that night, twenty-eight years ago, he had received the inspirational flash of the true meaning of electrolysis. The Willard Gibbs Medal was presented to him by the American Chemical Society. Arrhenius made many friends here. He spoke a clear, grammatical English, and his American audiences paid unstinted tribute to the genius of this Swede who could speak with as much lucidity and interest about his tiny, electrified, invisible ions, as he could about the vast universes building up in the celestial furnaces.

When the battle was over and the victorious Ionians had put away their armor, Ostwald, the picturesque standard bearer of radical theories, purchased a country estate in Gross Bothen, appropriately named it *Energie*, and settled down to further work in chemistry. Van't Hoff had died in 1911. Arrhenius, still as vigorous and acute as he had been a generation back, turned from his original triumph to other fields of speculation. His fertile mind became active in the field of astronomy. His meditations led him to a new theory—the birth of the solar system by the collision of great stars. Cosmogony was not the only branch of contemplative science he cultivated. He speculated as to the nature of comets, the aurora borealis, the temperature of celestial bodies and the causes of the glacial periods. He observed a strange periodicity of certain natural phenomena. He reflected upon the world's supply of energy, and studied the conservation of natural resources. Like Becher and Ostwald,

he dreamed of a universal language, suggesting a modified English. He was a true polyhistor. There was hardly a field of science which he left unnoticed, and in all he presented original if not altogether universally accepted ideas.

He did more than speculate. He hurried to Frankfort to study the treatment of disease with serums. He was one of those who watched Paul Ehrlich shoot injections of fluids into the blood stream of animals suffering from malignant diseases. Arrhenius marvelled at his dexterity and almost superhuman perseverance. He made a careful study of the work, and was the first to attempt to explain the chemistry of this serum therapy.

Arrhenius also spent three weeks at Manchester, in the laboratory of Rutherford whose new discovery was convulsing the scientific world. He wanted to learn more about it at first hand. The young New Zealander fascinated the Swede. Later, when he came to America, Arrhenius made a trip to the marine biological laboratory of Jacques Loeb. Arrhenius had met this experimental biologist while a student at Strassburg. He had come now to watch him demonstrate how the unfertilized egg of a sea-urchin could be made to develop by chemical means. It was one of the most thrilling experiences he had witnessed. A carefully prepared chemical solution had performed the function of wriggling sperm. Loeb had seen the importance of Arrhenius' theory of ionization and had made use of it in his study of the physiology of the lower animals.

Arrhenius pondered over the problem which Woehler had evoked when he synthesized urea. Could life on this earth have originated from the inanimate without the intervention of some vital force? Arrhenius could not believe this. Rather he felt that life on this planet had started from a living spore carried or pushed from some other planet by sunbeams or starbeams

until it finally fell upon the earth. Giordano Bruno, philosopher and poet, had been burnt at the stake in 1600, in the presence of Pope Clement VIII, for daring to say that other worlds might be blessed with life. This was no longer a dangerous idea but still revolutionary. Waves of light, Arrhenius maintained, actually pushed small particles of matter away from a star and brought them to the earth trillions of miles away. Arrhenius pictured these spores swept through the ether like corks carried by the waves of the ocean. He calculated the size of particles that could be moved by this light pressure, and found it to be within the limits of the size and weight of bacteria. He estimated the speed of this interstellar movement, and found it would take only three weeks for spores to be propelled from Mars to the earth, and nine thousand years from the nearest star. This theory of panspermia was challenged by the contention that any life-bearing seed would have perished in the frigid temperatures of interstellar space. But the theory was still safe, at least from this attack. Bacteria, subjected to temperatures very close to those reached between celestial bodies, lived after removal from liquid helium.

Such was the rich versatility of Arrhenius. He helped to popularize science by writing *Worlds in the Making*, *Life of the Universe*, *Destiny of the Stars*, and it is difficult to believe that this imaginative man, who possessed the literary ability of a poet, was not particularly interested in literature or the fine arts. His chief, perhaps his only delight, was in natural truth and natural beauty. He mixed very little in the political life of his country. Only on rare occasions did he talk about matters of government. He was opposed to the dissolution of the union of Norway and Sweden in 1905, but later his feelings in the matter changed, and he expressed the hope that Britain might give Ireland similar freedom. During the World War

he openly sympathized with the Allies, much as he owed to Germany during his early years of struggle.

In the early part of 1927, when Arrhenius was past sixty-eight, his advanced age and failing health compelled him to retire from the Directorship of the Nobel Institute. Sweden honored him without stint. He was granted a full pension for the remainder of his life. But scarcely had he left the Institute when news reached the world that this great figure had joined the eternal caravan of those who had watched the crucible. After a public funeral at Stockholm, his body was taken to Upsala and buried near the University of Berzelius and Linnæus. His life adds further testimony to the native genius of Sweden.

XIII

CURIE

THE STORY OF MARIE AND PIERRE

INTO a desolate region in Southern Colorado, in the latter part of 1920, came a small army of men to dig for ore. Every acre of America had been searched for such a mineral. Twenty years before it could have been imported from Austria, but conditions had changed. The Austrian Government had placed an embargo upon its exportation. So Joseph M. Flannery—he was the leader of this band of men—had to be satisfied with the sand in barren Colorado. There was nothing left to do but dig it out of this God-forsaken place.

Flannery's gang, three hundred strong, worked feverishly to collect tons of this sand called carnotite. They dug, sweated and often swore at the insanity of a boss who took them so far away from civilization. Into wagons they threw the canary yellow ore, and sure-footed burros hauled it over eighteen miles of roadless land half a mile above sea level. At the end of that mean trail Flannery had set up a concentration mill, the nearest water supply to the ore mines. In this mill five hundred tons of carnotite were chemically treated until only one hundred tons were left. This dirt was crushed into powder, packed into hundred-pound sacks and shipped sixty-five miles to Placerville. At this railway center the bags were loaded into freight cars destined for Canonsburg, Pennsylvania, twenty-five hundred miles away.

Here two hundred men were waiting to reduce this mass of powder to but a few hundred pounds. Workers skilled in the

handling of chemicals used tons of acids, water and coal to extract the invaluable treasure from the ore. Not a grain of the precious stuff hidden in this mound of powder was lost in innumerable boilings, filterings and crystallizations. Months passed, and at last all that remained of the Colorado sand was sent, under special guard, to the research laboratories of the Standard Chemical Company in Pittsburgh. And now began the final task—a careful and painstaking procedure of separation. A year's work to extract from these five hundred tons of dust just a few crystals of a salt!

For this thimbleful of glistening salt five hundred men had struggled with a mountain of ore. It was the most precious substance in all the world—a hundred thousand times more valuable than gold. For this gram of salt one hundred thousand dollars had been spent. A fabulous price for a magic stone!

Into a steel box lined with thick walls of lead, enclosed in a casket of polished mahogany, were placed these tiny crystals in ten small tubes. The precious casket, weighing fifty pounds, was locked and guarded in the company's safe to await the arrival of a visitor from France.

On May 20, 1921, in the reception room of the White House stood the President of the United States. Around him sat the French Ambassador, the Polish Minister, scientists, Cabinet members, judges and other men and women well known in the life of America. Before the President stood a frail, delicate figure dressed in black with a black lace scarf thrown over her shoulders. The room was fragrant with the scent of flowers—she loved flowers. This woman, who had been honored by kings and queens, stood here before the spokesman of a hundred thousand women. The President began to speak: "It has been your fortune to accomplish an immortal work for humanity. I have been commissioned to present to you this little phial of radium.

To you we owe knowledge and possession of it, and so to you we give it, confident that in your possession it will be the means to increase the field of useful knowledge to alleviate suffering among the children of man."

Radium—that was the magic element which had brought Flannery and his gang of men into desolate Colorado to dig for carnotite. Almost twenty-five years before, this woman, with but one assistant, her beloved Pierre, had accomplished the miracle of Flannery's five hundred men backed by a great modern financial organization with every scientific invention at its disposal. She had accomplished this wonderful work in an abandoned old shed in Paris. She had solved a problem and blazed a trail that Flannery and others have since travelled with less travail.

To-day, in the chief laboratory of the Radium Institute of the University of Paris, this woman, now past sixty, works silently with her test tubes and flasks while all the world waits eagerly for another miracle. The years have not completely broken this immortal bottle-washer. She is still above average height and broadshouldered. Her splendidly arched brow is crowned with a mass of wavy gray hair, once blond. Her soft, expressive, light blue eyes are full of sadness.

Prophetic Mendeléeff had met this woman when she was a young girl mixing chemicals in her cousin's laboratory in her native city of Warsaw. He knew her father, professor of mathematics and physics in the high school. Mendeléeff predicted a great future for Marie if she stuck to her chemistry. Marie looked up at her father, smiled, and said nothing. This modest and retiring girl, who had lost her mother when still an infant, loved her father passionately. Every Saturday evening he would sit before the lamp and read masterpieces of Polish prose and poetry. She would learn long passages by heart and

recite them to him. Her father was to her one of the three great minds of history—Karl Gauss, mathematician and astronomer, and Sir Isaac Newton were the other two. “My child,” remarked the professor when she confided this to him, “you have forgotten the other great mind—Aristotle.” And little Marie accepted his amendment in all seriousness.

Poland in those days was not a free Poland. It was part of Russia. Since 1831 the czarist government from St. Petersburg persecuted its refractory subjects who had unsuccessfully revolted in the hope of gaining complete independence. Tyrannical Russia imposed many restrictions. The Polish language was forbidden in the newspapers, churches and schools. The old University of Warsaw, whose professors were compelled to teach in the Russian language, was only a ghost of what it had once been. And the Russian secret service was omnipresent.

When Marie was seventeen, conditions at home compelled her to become governess in the family of a Russian nobleman. She kept in constant touch with the political affairs of her native country. Poland under Russian rule was suffering. Secretly there had sprung up groups of young men and women who vowed to overthrow the foreign oppressor. Among the most fervid of these plotters were some of her father’s students. They assembled clandestinely to teach in the Polish language those subjects they knew best, and Marie joined one of these groups. She had heard how, four years before her birth, Russian cannon had been fired upon women kneeling in the snow. She hated the Cossacks with their twisted hide whips. She even wrote for a revolutionary sheet—a dangerous practice, but she was as fearless as she was bitter.

The Russian police rounded up some of the young rebels. Marie escaped the net, but to avoid bearing witness against one of her unfortunate friends, she left Warsaw and the hated

Russians. In the winter of 1891, at the age of twenty-four, she arrived in Paris. Paris, the city of her scientific triumphs, was a place of bitter suffering during her first years. She rented a small room in a garret; she could afford no better quarters. It was bitter cold in winter time, and stifling hot in the summer. Up five flights of steps she was forced to carry water and the coal for the little stove that gave her some warmth. She had to stint, for her daily expenses, carefully figured, dare not exceed half a franc. Her meals were often reduced to nothing more than bread and chocolate. On the rare occasions when she allowed herself the luxury of a meal of meat and wine she had to acquire a new taste for these foods.

Marie did not mind these privations. She had come to Paris to study and teach. Europe was agog over the strange ions of a young teacher at Stockholm. Pasteur, old and broken in health, was the idol of France. Marie began to dream of a career in science. Strange that she should have such fancies at a time when science was a closed field for women. But she was dreamer enough to believe herself to be the woman whom destiny had selected to play a tremendous rôle in science. Had not Mendeléeff told her so? Quick as a flash, she made up her mind. She went to the Sorbonne and matriculated. It meant washing bottles and taking care of the furnace in the laboratory to meet expenses. But Faraday had done it—why could not Marie?

In the laboratory of Paul Schutzenberger, founder-director of the Municipal School of Physics and Chemistry of Paris, worked Pierre Curie, “a tall young man with auburn hair and limpid eyes.” He had graduated from the Sorbonne, and was now doing research work with his brother Jacques on electrical condensers and the magnetic property of iron. In 1894, at the home of a mutual friend, Marie met Pierre. “I noticed,” she



MME. MARIE SKLOWDOSKA CURIE

wrote later, "the grave and gentle expression of his face, as well as a certain abandon in his attitude suggesting the dreamer absorbed in his reflections."

They began a conversation which naturally concerned scientific matters. How else could Marie have approached this silent man? Then they discussed "certain social and humanitarian subjects." Marie was happy for "there was between his conceptions and mine, despite the difference between our native countries, a surprising kinship." Pierre, too, was joyful. He was amazed at the learning of this girl, and when he frankly admitted his astonishment, Marie twitted him with, "I wonder, Monsieur, where you can have imbibed your strange notions of a woman's limitations."

At twenty-two, Pierre had written, "Women of genius are rare, and the average woman is a positive hindrance to a serious-minded scientist." He was thirty-five now, and his contact with life had not changed his ideas much. Yet Pierre was captivated. He could not hide it, undemonstrative as he usually appeared. He expressed a desire to see this magnetic woman again. Marie walked on air. She wanted to know this dreamer. The sadness of his face drew her to him. Marie came to Professor Paul Schutzenberger and begged for permission to work beside Pierre. Her request was granted, for Schutzenberger was fond of Pierre. The shy, bashful, sixty-five-year-old scientist had devoted his life to the pursuit of science. Pierre, his young, idealistic disciple was a kindred spirit. So here in the laboratory of the Ecole Municipale, Pierre and Marie met day after day as teacher and pupil, suitor and admirer.

Pierre was beginning to experience a radical change of opinion about women. Before long Pierre, who might have been a man of letters, wrote to Marie: "It would be a lovely thing to pass through life together hypnotized in our dreams: your

dream for your country, our dream for science. Together we can serve humanity."

Marie was ready to go through life working at his side in the citadel of science. Their courtship was a short and happy one, and in July, 1895, they were married. Pierre, although brought up in a Catholic home, believed in no cult, and Marie at the time was not practicing any religion. Marie's father and sister came from Poland to greet them. It was a civil ceremony. Only a few friends were present. Marie wore the same dress as usual. It was a simple wedding. They had neither time nor money for elaborate ceremonies. They were both intensely happy.

The problem of furnishing a home was not a very serious one for two beings who cared nothing for convention. They rented three rooms overlooking a garden and bought a little furniture—just the barest necessities. Pierre was made professor of physics at the Ecole Municipale. He was earning now six thousand francs a year, and Marie continued with her studies. They allowed themselves no luxuries except the purchase of two bicycles for short week-end trips to the country, when they went picnicking alone among the chickens and flowers which Marie loved.

They were both back in the laboratory when, in Wurtzburg, William Conrad Roentgen discovered a ray of great penetrating power. On January 4, 1896, he described these X-rays, as he called them, to the members of the Berlin Physical Society. And hardly had the news of the discovery of these X-rays, which could penetrate solid objects and reveal the bony framework of a man, reached the world when an accident of great importance happened in the dark-room of the modest laboratory of Professor Henri Antoine Becquerel. It was known that phosphorescent substances after exposure to sunlight became

luminous in the dark. He was trying to find out whether such phosphorescent substances gave off Roentgen's rays.

It was not the sort of accident to reach the front pages of newspapers, although its result was world-shaking. From this accidental observation came a train of events which culminated in the triumphal work of Mme. Curie. Quite by accident, Becquerel had placed a piece of uranium ore upon a sensitized photographic plate lying on a table in his dark-room. Uranium salts had been known since 1789; they had been used to color glass. There was nothing very remarkable about this substance.

But one morning Becquerel found more than he expected. He noticed that in this completely darkened room the plate covered with black paper had been changed under the very spot on which the ore was placed. He could not understand this! Perhaps someone had been playing a prank. Now he deliberately tried the experiment to satisfy himself. The same effect was noticed. The photographic plate had been affected without any visible light and only under the uranium ore. How could he explain this strange phenomenon? He repeated the experiment with other ores containing the element uranium. In every case a spot was left on the plate. He analyzed the ores to determine the amounts of actual uranium they contained, and saw at once that the intensity of effect was directly proportional to the amount of uranium present in each ore.

Becquerel, famous scion of a family eminent for its researches on fluorescent light, was ready to draw a definite conclusion. He announced that it was the uranium salt present in each ore which was *alone* responsible for the strange effect produced on the photographic plate. But he did not cling very long to this belief. He tested the chief ore of uranium, pitchblende, a mineral which came from northern Bohemia. It was a strange rock; it puzzled him. Instead of giving a photographic

effect directly proportional to the amount of uranium present, this ore was much more powerful than its uranium content could account for. Becquerel now made the simplest inference. "There must be," he said, "another element with power to affect a photographic plate many times greater than uranium itself."

Marie's lucky day had dawned. Becquerel recognized in this Polish girl at the Sorbonne a scientist of the first order. He had watched her at work in the laboratory. Even as she weighed chemicals and adjusted apparatus he observed the dexterity of a trained and gifted experimenter. Yes, she had heard the startling news. He presented the problem to her. Would she undertake this piece of research?

She talked it over with Pierre. Her enthusiasm captivated him. She told her husband that, in her opinion, the increased activity of the ore from Bohemia was due to a hitherto unknown element more powerful than uranium. "This substance," she told Pierre, "cannot be one of the known elements, because those have already been examined; it must be a new element." Pierre was working on crystals, and she on the magnetic properties of metals in solution. Both dropped all their work to join in the great adventure of tracking down the unknown cause of the great power of pitchblende. Mendeléeff, hearing of this, consulted his Periodic Table. There was room for such an element. Marie was bound to find it.

The Curies had no money to undertake the search—they borrowed some. Neither had they any idea how much time it would take. They wrote to the Austrian Government which owned the pitchblende mines. The Austrian officials were willing to help. Soon, from the mines of Joachimsthal, there arrived in Paris one ton of pitchblende. Marie was sure that in this hill of sand the undiscovered metal lay hidden.

Those were hectic days for the Curies. They worked incessantly. Not a moment was wasted; the search was too alluring. They boiled and cooked the great mound of dirt, filtered and separated impurity after impurity. When the poison gases threatened to stifle them under the leaky roof of their improvised laboratory, Marie herself lifted and moved large vats of liquid to the adjoining yard. It was the work of men, protested Pierre, but Marie told him she was strong. She could do superhuman work. For hours at a time she stood beside the boiling pots stirring the thick liquids with a great iron rod almost as large as herself. The stifling fumes made that shed a hell, but to Marie beside her Pierre it was heaven. There stood Pierre lifting great batches of heavy chemicals and dreaming of scientific conquests.

"We lived in a preoccupation as complete as that of a dream," remarked Marie years later. When the cold was so intense that they could not continue their work, she would brew some tea and draw closer to the cast-iron stove. The bitter winter of 1896 came and found that mad couple still laboring in their hangar. Marie was bound to break under this terrific strain. Soon pneumonia made her take to bed, and it was three months before she was strong enough to return to her boiling cauldrons. Pierre, too, at the end of each day's work was broken with fatigue. But the search went on.

In the month of September, 1897, a daughter was born to the Curies. Pierre's boyhood friends came to congratulate them. Debierne, discoverer of actinium, Perrin, the molecule counter, and Georges Urbain were among the visitors. The mother, as she lay helpless, kept thinking of her job under the shed. When the child was but a week old, Marie walked into that workshop again to test out something that had occurred to her as she lay in bed. However, she cared for baby Irene with the same devo-

tion she gave to science. Pierre, of course, helped her, and in the evenings when he returned from the shack to assist Marie, they spoke now of three things—baby Irene, science and Poland.

It became a serious difficulty for Marie to take care of Irene and continue her scientific work. But a way out was soon found. Pierre's mother had just died and his father, a retired physician with a taste for research, came to live with them. Grandpa watched and cared for his little girl, while her parents grappled with a mound of sand.

In the meantime, the pile of pitchblende had dwindled down to a hundred pounds. They made their separations by a method of electrical measurement which exposed the more powerful fractions of their material from the inactive parts. Often in the midst of some chemical operation which could not be suspended, Pierre would work for hours at a stretch, while Marie prepared hasty meals which they ate as they continued their task. Another year of heroic work. Again Marie was ill. Pierre was ready to give up, but Marie was courageous. In spite of all their sufferings, Marie confessed that "it was in that miserable shed that we passed the best and happiest years of our life."

They were fighting a lone battle. No one came to help. When almost two years of constant work were behind them, the news of the great experiment leaked out, though they had tried to keep it secret. Pierre was invited to accept a chair of physics at the University of Geneva. It was a tempting offer. He made the trip to Switzerland, but was back before long. The great work would be in danger if he were to accept. Marie was happy again.

By now they had extracted a small amount of bismuth salts which showed the presence of a very active element. This element appeared to be about three hundred times as potent as uranium. Marie set to work and isolated from this bismuth salt

a substance which resembled nickel. Perhaps it was a new element. She subjected it to every known test, and in July, 1898, she announced the discovery of a hitherto unknown element, which she named "polonium" in honor of her beloved country. The reality of this new element was at first questioned. It was suspected to be a mixture of bismuth and some other element. But its existence was soon confirmed.

Others might have been satisfied with this discovery of an element hundreds of times more active than uranium. But not the Curies. They kept working with portions of that ton of pitchblende, now boiled down to amounts small enough to fit into a flask or test tube. This fraction of chemicals appeared to possess properties much stronger than even polonium. Could it be possible? Marie never doubted it. She looked at this bit of material, the residue of two years of tedious extractions by repeated crystallizations. It was a very tiny amount; she must be more than careful now. She examined every drop of solution that came trickling through the filter. She tested every grain of solid that clung to the filter paper in her funnel. Not an iota of the precious stuff must escape her. Marie and Pierre plodded on. One night they walked to the shed. It had been a dissecting room years ago; it was now a spookier place. Instead of "stiffs" laid out for dissection, they "saw on all sides the feebly luminous silhouettes of the bottles and capsules containing their product. They were like earthly stars—these glowing tubes in that poor rough shack." They knew that they were near their goal.

Bémont, in charge of the laboratory at the Sorbonne, was called in to help in the final separations. Bottle after bottle, crystallizing dish after crystallizing dish, was cleaned until not a speck of dust was left to contaminate the last product of their extractions. Marie did the cleaning. She was the bottle washer

who was first to gaze upon a few crystals of salt of another new element—the element *radium*, destined to cause greater overturning of chemical theories than any other element that had ever been isolated. This was the end of that long trail under the abandoned old shed in Paris.

Pierre was given the position of professor of physics at the Sorbonne, and Marie was put in charge of the physics lectures at the Higher Normal School for Girls at Sèvres, near Paris. She taught, studied, worked in her laboratory and helped take care of Irene. Baby Irene was growing up. In her spare moments Marie found time to make little white dresses. She knitted a muffler for her, and washed and ironed the more delicate garments. Even now she had to watch her pennies. Pierre was superb. He helped her at every turn.

Marie was ready to study every property of the queer new element. She intended to include this work in her thesis for the degree of doctor of science; as a teacher she needed this title. After five more years of research, she presented her thesis. The examining committee of professors was made up of Henri Moissan, inventor of the electric arc, Gabriel Lippmann, developer of color photography, and Bonty. Marie presented her complete work on radioactivity, as she named the effects produced by polonium, radium, uranium, and similar elements. She described radium, an element millions of times more active than uranium. Unbelievable, yet true! The professors were astounded by the mass of original information brought out by this woman. They hardly knew what to ask. Before her, these eminent scientists seemed mere schoolboys. It was unanimously admitted that this thesis was the greatest single contribution of any doctor's thesis in the history of science.

The news was made public. A strange element had been discovered by a woman. Its salts were self-luminous; they shone in

the dark like tiny electric bulbs. They were continuously emitting heat in appreciable quantities. This heat given off was two hundred and fifty thousand times as much as that produced by the burning of an equal weight of coal. It was calculated that a ton of radium would boil one thousand tons of water for a whole year. This new element was the most potent poison known to mankind—even acting from a distance. A tube containing a grain the size of a pinhead and placed over the spinal column of a mouse paralyzed it in three hours; in seven hours the animal was in convulsions and in fifteen hours it was dead. Radium next to the skin produced painful sores. Pierre knew this. He had voluntarily exposed his arm to the action of this element. Besides, his fingers were sore and almost paralyzed from its effects. Becquerel had complained about it to Marie. "I love it," he had told her, "but I owe it a grudge." He had received a nasty burn on his stomach from carrying a minute amount of radium in a tube in his vest pocket when he went to London to exhibit the peculiar element to the Royal Society. Its presence sterilized seeds, healed surface cancer and killed microbes. It colored diamonds and the glass tubes in which it was kept. It electrified the air around it, and penetrated solids.

The world marveled at the news. Here was another one of nature's surprises. Chemists were bewildered. A woman had not only pushed back the frontiers of chemical knowledge—she had discovered a new world waiting to be explored. From every laboratory on the face of the earth came inquiries about this magic stone. The imagination of the world was kindled as by no other discovery within the memory of man. Overnight the Curies became world famous.

Then began the tramp of feet to the hiding place of the Curies. The world was making a beaten path to the door of these pioneers. Tourists invaded Marie's lecture rooms. Jour-

nalists and photographers pursued them relentlessly. All sorts of stories came back of this strange couple—Pierre the reticent, dreamy, publicity-hating philosopher, and Marie the sad-faced mother who sewed and cooked and told stories to her dark little girl. Newsmongers invaded the privacy of her home and went so far as to report the conversation between Irene and her little friend, and to describe the black and white cat that lived with them. They described Mme. Curie's study; "a writing table, two rather hard armchairs, two others with straw bottoms, a couple of bookcases with glass doors through which you see volumes, papers, and vials thrown together pell mell, an iron stove in the middle of the room. Curtains, rugs, and hangings absent, letters and telegrams piled high on the table."

Marie and Pierre complained. "These are days when we scarcely have time to breathe, and to think that we dreamed of living in a world quite removed from human beings!" They wanted to be left alone, but it was of no avail. Letters, invitations, telegrams, visitors bothered and distracted them. The world clamored for the Curies. They must come out of their laboratory for a few hours at least. Lord Kelvin, England's greatest scientist, personally invited them to come to London to receive the Davy Medal of the Royal Society.

This was only the beginning of still greater honors, many of which they refused. They would rather have laboratories than decorations, was Pierre's reply, on being offered the ribbon of the Legion of Honor. Within a few months the Nobel Prize was awarded them, to be shared with the man who had started Marie on her triumphant research—Becquerel of Paris. The money from this prize was soon gone, to pay the debts incurred to keep their experiments going. They could easily have capitalized their discoveries, but they had not labored for profit. Their work was one of pure science, their sole object to serve hu-

manity, and they refused emphatically to patent their discoveries. Almost a century before, Sir Humphrey Davy, too, had been urged to patent his newly invented miner's safety lamp, which could have brought him an annual income of ten thousand dollars. He had refused. "I have enough," he had said, "for all my views and purposes. More wealth would not increase either my fame or my happiness."

The case of the Curies was so different. Theirs was still a severe struggle. And yet they refused fabulous profits. Every crystal of radium salt which they wrenched from mountains of rock they turned over to hospitals without charge. When, in February, 1905, they succeeded in isolating a few grains of the new salt, they sent it to the Vienna Hospital in recognition of the help of the Austrian Government in providing them with the first load of pitchblende. Even that gram of radium salt, gift of American womanhood in 1921, was willed at once to the Institute of Radium of Paris for exclusive use in the *Laboratoire Curie*.

Marie's joy had now reached the skies. Irene was now a lovely little child of seven. Pierre had lost some of his sadness. Things were becoming a little easier for them. Then another baby daughter came—Eve Denise. Their cup of happiness was filled to the brim. But death was soon to stalk in the house of the Curies. In the afternoon of the 19th of April, 1906, a messenger knocked at the door of their home at 108 Boulevard Kellermann. One of the loveliest unions in all the history of science had come to a tragic end. A few minutes before, Pierre had been speaking to Professor Perrin at a reunion of the Faculty of Sciences. They had talked about atoms and molecules and the disintegration of matter. Pierre was on his way home. As he was crossing Rue Dauphine a cab knocked him down,

and as he fell, the wheels of a heavy van coming from the opposite direction passed over his head. He died instantly.

Marie listened to the story. There was no tearing of hair or wringing of hands. Not even tears. She kept repeating in a daze, "Pierre is dead, Pierre is dead." This blow almost struck her down. She mourned silently. Messages of condolences came pouring in. Rulers of nations and the most eminent scientists of the world shared her great grief. For a time it seemed she would never be able to resume her work. Within a few weeks, however, she was back in her laboratory, more silent than ever. She was to consecrate the rest of her life in the laboratory to the memory of Pierre.

Then France made a wonderful gesture. Marie was asked to occupy the chair of physics vacated by the death of her husband. This was indeed contrary to all precedent. No woman had ever held a professorship at the Sorbonne. Tradition was smashed. There was muffled whispering in the halls of the University of Paris. Men with long beards shook their gray heads against such a blunder. Some believed that whatever inspiration there had been in her work on polonium and radium was due to the fact that she had been working under the guidance and stimulation of a profoundly imaginative man, whom, furthermore, she loved very dearly. That, they whispered behind closed doors, was the only reason for her creative work in the past. "Wait," they said, "a few years more, and Marie will have disappeared from the stage like a shadow." They dare not be heard lest they wound more deeply the broken heart of Mme. Curie. There was no open opposition. The magic word radium stilled the voices of those who might have cried out.

Then it was announced that Mme. Curie was to lecture in the great amphitheatre of the Sorbonne. This was to be her first lecture. Men and women from all walks of life came to Paris

to hear her, members of the Academy, the faculty of science, statesmen, titled ladies and great celebrities. Lord Kelvin, Ramsay and Lodge, were among the audience. President and Mme. Fallières of France had come, and King Carlos and Queen Amelia of Portugal were also present to do honor to this woman. "On the stroke of three an insignificant little black-robed woman stepped in through a side door, and the brilliant throng rose with a thrill of homage and respect. The next moment a roar of applause burst forth. The timid little figure was visibly distressed and raised a trembling hand in mute appeal. Then you could have heard a pin drop."

She began her lecture in a low, clear, almost musical voice. There was no sign of hesitation now. She spoke French with but a slight Polish accent. There was no oratorical burst of enthusiasm; she was like a passionless spirit, the very personification of the search for scientific truth. Her audience expected to hear her extol the work of her predecessor. "When we consider," she began, "the progress made by the theories of electricity ——" Her listeners were spellbound. Not a word of her great tragedy. She continued Pierre's last lecture on polonium almost at the exact point where he had left off. When she finished, there was a burst of applause that rang even in the ears of the hundreds that remained outside unable to gain admittance. None waited for the report of this historic lecture with more eagerness than her sister Dr. Dlushka at Zakopane in the Carpathian Mountains, and her brother Dr. Sklodowska in the hospital of her native Warsaw. And old Mendeléeff, dying in St. Petersburg of infected lungs, smiled again as he received the news. Andrew Carnegie, hearing of it in America, provided a fund to help her research students.

There were a few who still whispered about tradition, inspiration, women and science. They still doubted the individual

greatness of Marie. She heard those faint rumors, but said nothing. She was as silent as a sarcophagus.

The element radium must be isolated—free and uncombined with any other element. That was the task she set herself. Debierne, boyhood friend of Pierre, was to aid her. Radium was a stubborn element. It was difficult to pry it loose from its chloride. And there was so little of the salt to work with! Numerous methods of separation were tried unsuccessfully. Marie lived in the laboratory. She never took time for the theatre or the opera; she refused all social engagements. France hardly saw her. Finally, in 1910, Mme. Curie passed an electric current through molten radium chloride. At the negative mercury electrode she began to notice a chemical change. An amalgam was being formed. She skillfully gathered up this alloy and heated it in a silica tube filled with nitrogen under reduced pressure. The mercury boiled off as a vapor, and before her eyes lay at last the elusive radium—brilliant white globules that tarnished in the air. This was her crowning achievement. It was fitting that she who had first isolated its salts should be the first to gaze on the free element itself.

Here was a piece of brilliant work performed by Marie without Pierre beside her. The whispers were stilled forever. For this epochal work Marie became the recipient of the Nobel Prize for the second time, the only scientist ever so signally honored.

Mme. Curie was persuaded to become a candidate for membership in the Academy of Sciences of Paris, which Pierre had joined in 1905. The taboo of sex was again raised in that circle of distinguished scientists. No woman had ever been elected to that body. There was "an immutable tradition against the election of women, which it seemed eminently wise to respect." Level-headed scientists suddenly became excited. There was

much heated discussion. Marie, of course, remained in the background. When, on January 23, 1911, the vote was taken, Mme. Curie failed of election by but two votes, and Professor Edouard Branley, inventor of the coherer used in the detection of wireless waves, was selected instead. France never lived down this episode of bigotry.

In the summer of 1913 Mme. Curie went to Warsaw to found a radium institute, returning to the University of Paris in the fall. Then, in 1914, while the hordes of German soldiers were advancing almost within sight of the Sorbonne, this brave woman made a secret and hurried trip to Bordeaux, with a little package safely tucked away in a handbag. While great guns roared the opening of the Battle of the Marne, and Paris taxicabs filled with light-blue uniformed men dashed madly out of the city on their way to the front, this woman fled from Paris for the South. She ran away, not for fear of German bayonets, but in dread lest the little tube she carried in her bag might fall into the hands of the enemy. When the tube of radium was safely hidden in Bordeaux, Marie made haste to return to Paris to do her bit for the country of her adoption. Air raids did not disturb her now, nor the dangers of a ruthless invasion.

Mme. Curie planned a great undertaking. She collected all the available radiological apparatus in Paris; there was very little outside of the capital. She issued a call for young girls to be trained in the use of this wonderful new tool of medicine. One hundred and fifty girls were selected and for eight weeks she lectured and trained them to be radiological operators. Irene, now seventeen, who had refused to leave Paris under bombardment, was among the volunteers.

Mme. Curie learned to drive a car and transported instruments to be installed in the army hospitals. And while this woman, then almost fifty, loaded heavy pieces of apparatus,

Irene did ambulance service near Amiens, where the old cathedral shook under incessant cannonading. Irene even went into Ypres where chlorine choked the lives out of helpless soldiers. Mother and daughter worked like Amazons.

When the invading German army had been driven back, Mme. Curie returned to Bordeaux, packed the precious tube of radium salt in her bag, and brought it again to Paris. The first year of the war saw the completion of the Radium Institute of the University of Paris. Curie was made Director. In a little room in the Institute on rue Pierre Curie, devoted to X-rays and the extraction of radium, she worked feverishly all through the war. While the slaughter of thousands went on, Marie worked heroically to save a few battered, shattered hulks. She loved freedom more than she hated war, and when the peace was signed, she declared: "A great joy came to me as a consequence of the victory obtained by the sacrifice of so many human lives. I have lived to see the reparation of more than a century of injustice that has been done to Poland." Her native land was now an independent country. Professor Ignace Moscicki, who also works with beaker and test tube in the chemical laboratory, is now President of this Republic.

In 1921 she was asked what she preferred to have most and promptly replied: "A gram of radium under my own control." This woman who had given radium to mankind owned none of the metal herself, though the world possessed one hundred and fifty grams of it. Within a few months, however, a gram of radium, gift of the women of America, was hers.

Eight years passed and again America showed its profound interest in Mme. Curie. With the radium which she received in 1921 she was also given a small annuity. This she immediately used to rent some radium for a hospital in Warsaw. While in the hospitals of New York there were fourteen grams



MME. CURIE AND OWEN D. YOUNG
During her last visit to America in October, 1929

of the salt of this curative element, in all of Poland with its twenty-five million inhabitants there was not a gram of this substance. Mme. Curie felt this keenly but was powerless to help. Her friends invited her to come to New York to receive another gift which would enable her to give Poland a gram of radium.

Her doctors were opposed to another trans-Atlantic trip. She was anemic and weak. Her heroic sacrifices for science had played havoc with her strength. Yet she insisted on undertaking this journey, and risked her life once more. Her visit, however, was made as confidential as possible. On October 15, 1929, she arrived in New York. All red tape was cut. She was given the freedom of the port. A distinguished delegation quietly met her at the pier. She was spared the American ordeal of handshaking which had so distressed her on her previous visit.

President and Mrs. Hoover met this pale-faced woman at the front door of the White House and after an informal family dinner she was escorted to the National Academy of Sciences. Here the President of the United States presented her with a silver-encased draft for fifty thousand dollars, with which to purchase a gram of radium in Belgium. Since the discovery, in 1921, of rich radium ore deposits in upper Katanga of the Belgian Congo, Belgium had cut the price of radium in half. Otherwise she would have again received American-produced radium.

During this second visit she remained in seclusion most of the time except when she attended a few public functions. In New York she was the guest of honor at a dinner of the American Society for the Control of Cancer. In Detroit she took part in the celebration of the Golden Jubilee of Edison's perfection of the incandescent electric lamp. She also attended the ceremonies in connection with the dedication of the Hepburn Hall

of Chemistry of St. Lawrence University at Canton, New York, where a bas-relief of her was unveiled. Here the honorary degree of Doctor of Science was added to the other degrees which Yale, Columbia, Wellesley, Smith and the Universities of Chicago and Pennsylvania had already conferred upon her. Owen D. Young invited her to visit the Research Laboratories of the General Electric Company through which she was conducted by Whitney, Langmuir and W. D. Coolidge—as eminent a triumvirate of scientists as ever graced any sanctum of science.

On November 8, she embarked for France to return once more to the laboratory of the Curie Institute. France could not see America outdo her in veneration for this great woman. Before she returned, the French Government voted a million and a half francs for the construction of a huge factory-laboratory for the study of radioactive elements. The plans for this unique laboratory had been outlined by Mme. Curie and Professor Urbain, Director of the Chemical Institute of the University of Paris.

More than twenty-five years have passed since presidents and kings first came to the Sorbonne to honor this woman. Her slow, noiseless step is still heard there. And as one watches this indomitable spirit, her long supple fingers fondly handling the potent salt of her creation, one wonders which is greater, her epoch-making scientific conquests or the nobility of her self-effacing life absorbed in the adventure of science.

XIV

THOMSON

HE TRAPS THE MOTE IN A SUNBEAM

WHILE the Curies in Paris toiled in a workshop that closely resembled the laboratories of the ancient gold cooks, in a cloistered cell at Cambridge a group of young Englishmen were battering down the walls that held the tiny atom intact and indivisible. The Curies had given them the tool of power with which to lay siege to the citadel of the atomic world.

In 1897, when the search for radium was leading the Curies to glory, the bubble of the atom as the ultimate reality of matter was pricked by a great Master who stood at the fountainhead of a brilliant group of disciples gathered in the Cavendish Laboratory of Experimental Physics. Chemistry had borrowed lavishly from the storehouse of physics. Now the great advancing problems in chemistry were questions which the physicists were better equipped to solve, but the chemist worked hand in hand with the physicist—here was a great scientific entente. The borderland between physics and chemistry was obliterated.

The Master was a man familiarly known to his students as "J. J." His rise in the ranks of pure science had been phenomenal. J. J. Thomson was born near Manchester towards the close of the year which witnessed the death of another dreamer in pure science—Amedeo Avogadro. While originally wishing to become a practical engineer, his career in pure science was due, strangely enough, to its being impossible for him to make the necessary arrangements for engineering. He attended Owens

College, where a scholarship for research in chemistry had recently been made possible by a fund of twenty thousand dollars raised by the citizens of Manchester in memory of John Dalton, architect of the atoms. From Owens College he went to Cambridge, there to become the third of that trinity of discoverers of the ultimate particles of matter—Atoms, Molecules, Electrons.

At Cambridge, Lord Rayleigh was in charge of the Cavendish Laboratory, established hardly a decade before by a descendant of the family of Cavendish. Rayleigh was the successor to the first occupant of the chair of experimental physics, James Clerk-Maxwell, that great genius who laid the foundations of the electro-magnetic theory of light. Five years later Lord Rayleigh decided to resign. Asked to name his successor, he pointed without hesitation to his most gifted pupil, Joseph John Thomson. This news created an uproar. A lad of only twenty-eight mentioned as successor to Clerk-Maxwell and Rayleigh! What if Thomson had shown unmistakable signs of genius when, at twenty-five, he had won the Adams Prize for an essay which attacked as unscientific the theory that atoms were vortices or whirlpools in the ether. This essay was unquestionably an admirable presentation of the fallacies of the Vortex Theory. But he had done very little experimentation. Most of his work was in mathematics, and even in this field his record of honors so far had not been the highest. In the traditional Tripos at Cambridge, an examination for honors in mathematics, he had come out not at the head of his group, but only as Second Wrangler. But then even Maxwell had been beaten for Senior Wrangler honors.

Three eminent scientists constituted the Board of Electors which was to make the final choice—Lord Kelvin, the Scotchman who in Glasgow worked out the intricate problems of the

first Atlantic Cable; Sir George Gabriel Stokes, investigator of fluorescence; and Professor George Howard Darwin, second son of Charles Darwin. They saw inside that massive head of Thomson an imaginative yet crystal-clear mind with powerful penetrating power. The lad from Manchester was chosen. "Shades of Clerk-Maxwell," declared one well-known professor, "things have come to a pretty pass in the University of Newton when mere boys are made professors." Michael Pupin, the eminent American scientist, coming from a cracker factory in New York to study physics under Clerk-Maxwell at Cambridge was frightened away when he learned that a young lad, only two years his senior, had been put at the head of the famous Cavendish Laboratory. "I thought he was too young to be my teacher of physics," he complained.

And so it came about that a mere boy filled the chair of two illustrious predecessors, and under his leadership the Cavendish Laboratory became the dominant center of scientific research in the world. Here was carried on more important research per square foot than in any other part of the earth. Here men's minds soared to heights never dreamed of before. The spirit of the boy Thomson was to pervade that sanctum of science for nearly half a century.

In the lightning flash which splits the heavens Thomson saw a force in which lay the key to the mystery of the material world. He chose as his field of research the realm of electricity. A year before he entered Cambridge, Thomson had heard of a peculiar glass tube or globe constructed by his countryman, William Crookes. By means of a vacuum pump, Crookes drew almost all of the air out of this tube so that only an infinitesimal fraction of the original molecules of air remained in his sealed glass container. With the aid of an induc-

tion coil he discharged a high voltage current of electricity through his highly evacuated globe.

Then Crookes observed a ghostly fluorescence issuing from the negative plate, or cathode, of the glass tube. What could account for this spooky light? The molecules of the thin air in his tube were illuminated by a pale, dim light, and a greenish yellow fluorescence formed on the glass walls of the instrument. Crookes was not the first to look upon these strange rays of light. William Watson, English apothecary and physician, almost a century and a half before had passed the electric energy of his improved Leyden jar through a glass tube three feet long, partly exhausted of air. "It was," he recorded, "a most delightful spectacle when the room was darkened to see the electricity in its passage. The coruscations were of the whole length of the tube between the plates."

But was it really light he beheld? Light, as every responsible professor had taught, was neither ponderable nor material. Yet these *cathode rays* could be made to bend under the influence of a strong electromagnet brought near the tube. Crookes was flabbergasted. Light, and yet unmistakably matter! How to reconcile the two irreconcilables? He could not.

For want of a better name, he termed these cathode rays a *fourth state of matter*—for it was neither gas, liquid, nor solid. He ventured another name—*radiant matter*. That was the best he could do. But the mystery still remained. Crookes, as he gazed upon those cathode rays and saw the flight of myriads of disembodied atoms of electricity, just missed discovering the Electron.

However, Crookes, son of a tailor, had done valiant service. He had given mankind a new instrument of discovery. With it Roentgen discovered X-rays, and with it Thomson was to accomplish still greater wonders. This Crookes' tube was the fore-

runner of the super five-foot cathode tube through which to-day, in the Research Laboratory of the General Electric Company at Schenectady, a stooped, near-sighted, curly-haired, middle-aged man, Dr. W. D. Coolidge, shoots a million volts of direct current electricity and produces effects which are staggering.

Thomson was to learn more about this "borderland where Matter and Force seemed to merge into one another, that shadowy realm between Known and Unknown." He began to construct these strange big-bellied cathode tubes, and worked his vacuum pumps until the air inside the tubes was twenty million times thinner than the air he breathed. There were only seven students working in his laboratory at the time. He called Richard Threlfall to his side to work with him on the passage of electricity through these tubes. He sent currents of high potential through them and watched the ghastly glow of the cathode rays in the blackness of his research den. They were spooky streams of light. Thomson was like a conjurer trying to evoke the spirit of the great secret of matter.

He wondered at the cause of the undeniable bending of that beam of light by a magnet. The stream of light was deflected as if it were made up of so many iron filings attracted by a magnet. He began to understand why Crookes, pulling at his long curled mustache, had been puzzled almost to madness.

Thomson varied the conditions of his experiments. He changed the degree of evacuation of his tubes. He used different cathodes, altered the intensity of electricity which was sent through the tubes. Years passed. His data kept piling up, and as the facts and figures mounted, Thomson's mind, too, soared high.

In 1890, in the midst of his researches, he married Rose Elizabeth, daughter of Sir George E. Paget, and two years later, George Paget Thomson was born to follow in the foot-

steps of his father. In 1894 he was elected President of the Cambridge Philosophical Society, and then made a trip to America to lecture at Princeton University on "Electrical Discharges Through Matter." He was gradually evolving a new theory. It was not to be a creed; to him any theory was only a plan or guide to work by.

Faraday's study of electrolysis had led him to suspect atoms of electricity and his laws of electrolysis strongly hinted at discrete particles of electricity. Helmholtz of Potsdam, in 1881, before the Royal Institution, was actually bold enough to declare that "electricity is divided into definite elementary portions which behave like atoms of electricity." That same year Thomson, at twenty-five, had measured the mass of a small pith ball before and after electrification to determine whether electricity possessed mass. He examined the phenomenon of a moving electric discharge and found that more work was required to give a definite speed to an electrically charged sphere than to the same sphere uncharged. This astonishing result indicated to him that an electric charge possessed inertia—the distinguishing characteristic of all *matter*.

He was back at Cambridge now, as busy as ever. Then one Friday evening, on the 30th of April, 1897, Joseph John Thomson announced to the Royal Society his epoch-making conclusion of twenty years of work. "Cathode rays," he declared, "are particles of negative electricity." He denied the ultimate reality of the atom! Since 1800 the Daltonian atom had been regarded as the primordial substance from which every material of the universe had been built. It had been generally accepted as the indivisible brick of the universe. Another sacred cow of chemistry had been slaughtered!

More than two centuries before, Robert Boyle, revered by Englishmen as the father of chemistry, had declared the ele-

ments to be "the practical limits of chemical analysis." He believed them to be substances "incapable of decomposition by any means with which we are at present acquainted." But, he added, "there may be some agent so subtle and so powerful as to be able to resolve the compounded corpuscles into those more simple ones, whereof they consist." Robert Boyle, of course, never dreamed of the new chemistry and the new physics. But Thomson did. He had an abiding faith in the simplicity of nature. "There must be something simpler than ninety-two separate and distinct atoms of matter," he whispered to himself. And now he had found that something!

It was the *electron* or corpuscle, as he had first called it. The stream of cathode rays which the magnet had deflected was made up of electrons, torn away from the atoms of the gas in the tube. These electrons were part of the atom, and were alike no matter where they originated. They were negative particles of electricity and were ponderable. The electron was also the smallest particle of matter which moved with a velocity of 160,000 miles per second. Every one of the ninety atoms of the chemist was built of these same electrons.

That is what Thomson told the world. Would reputable scientists believe him? Thomson was not a Becher, creator of phlogiston. He was going to establish definitely the existence of his chemico-physical monstrosity—a disembodied atom of electricity. He was going to prove its reality by calculating its mass. No man ever set himself a more difficult task. And no man, without the dexterity and imagination of Thomson, could have ever hoped to succeed.

He measured the amount of bending which the cathode stream of electrons suffered in the presence of magnets of known strengths. Through a maze of experimental details, figures and calculations, Thomson arrived at a number. He had

determined the ratio of the electric charge of the electron to its mass—the “ e/m ,” as it is called. This mathematical genius and experimental wizard was as infallible as any human experimenter could be. He announced the calculated mass of the electron as less than two thousand times that of the atom of hydrogen, the lightest substance hitherto known.

The world was not altogether convinced. True, the latter part of the nineteenth century was bewildering in its great scientific discoveries. Men had seen such vast miracles and revolutions in science, that they were afraid to deny the validity of Thomson's work. But still they doubted. After all, they said, it was only a “calculation.” Thomson himself was not satisfied.

He called in his research students. Their number had doubled since he had been put in charge of the laboratory. Nearly every afternoon they met in his room for tea. “J. J.” was at his best at these informal gatherings. He was wonderfully human. Science was not the only subject discussed. “Thomson's vigorous radical utterances were very warmly discussed and often among the cosmopolitan collection of students political discussions became very animated.” The conversation would often turn to less serious matters. “The gossip of the laboratory went round and a story had to be a pretty tall one if he did not manage to cap it.” John Zeleny, now Professor at Yale University, vividly remembers those days when he worked with Thomson on the mobilities of gaseous ions. “We lived,” he recalls, “in an atmosphere sparkling with new thought, and enjoyed a free and happy comradeship.”

The Master talked over his own researches with his students. The whole subject of the reality of the electron was discussed. There were two Wilsons in his laboratory at the time. Suddenly he turned to C.T.R.—that was the way he addressed Charles Thomson Rees Wilson. This boy, too, had originally

come from Owens College. Thomson had been watching him at work with his "dust counter." Wilson had noticed that particles of dust acted as nuclei around which moisture condensed as tiny droplets of water when the air was suddenly cooled by expansion. These dust particles were too small to be photographed, but when they were surrounded by droplets of water they became easily visible and could be photographed. He thus devised an ingenious method of counting dust particles of the air.

Thomson spoke to him. He had that extraordinary gift of stimulating originality in his students. His whole laboratory smacked of dexterous schemes and subtle, ingenious devices for cornering nature in its most inaccessible places. In such an atmosphere C.T.R. had worked. Thomson asked him this question: "Can you photograph the elusive electron?" There was nothing left to do but attempt it, even though it came perilously near the work of a magician.

That dust counting had given Wilson some wonderful training. Perhaps an electrical particle would act in the same way as tiny dust specks. He tried the experiment, and after innumerable trials he triumphed. He saw through his powerful microscope water vapor condensing into tiny droplets around Thomson's negatively charged particles or electrons.

And now to prove the objective reality of electrons to every Tom, Dick and Harry of a chemist or physicist. If he could only capture these moving particles long enough to imprint them on a photographic plate! It savored of the miraculous. One atom, two thousand times heavier than an electron,—even a million uncharged atoms could not be photographed, yet C.T.R. felt that he could trap a single electron. For nothing was impossible to a disciple of the Master.

Wilson began to work on a super-camera which would photo-

graph an electron. It was a tremendous job. Months passed. The Curies had discovered radium, Marie had read her immortal thesis on radioactivity, and still he experimented. In 1903 Thomson left for the United States for the second time, to lecture at Yale and Johns Hopkins. He returned with another bundle of degrees to find C.T.R. still constructing his camera. And while the Master was being honored with the Nobel Prize and knighthood, C.T.R. still worked. Then, in 1911, the work was completed. "The photographic plate is placed in a light frame supported by a silk thread. The plate is kept at the top of a light-tight metal case and as soon as the desired conditions are obtained, the plate is lowered by means of a winch, the axle of which works in an air-tight ground joint." The device was a masterpiece of workmanship. Would it work?

The whole camera was sealed in a glass chamber in which electrons could be produced at will. Charcoal tubes were attached to the camera and immersed in liquid air, for charcoal at this very low temperature absorbed gases greedily thus keeping the chamber highly evacuated. When everything was in readiness the plate was lowered into the field of the electrons, and a photograph was taken. The vacuum in the apparatus was destroyed, the film removed and developed. Wilson had won again. He had arrested the flight of electrons and had drawn their pictures. A tangled skein of threads representing the path of single electrons after expulsion from their atoms appeared on the plate. These fog tracks of electrons were faint, to be sure, but they were undeniably there. Wilson had imprisoned a single electron, surrounded by a droplet of water, moving dizzily through space. Here was incontestable proof of the reality of the electron.

In the meantime, Thomson and another of his English students, Harold A. Wilson, now professor at Rice Institute,

Houston, Texas, were attempting with the aid of C.T.R.'s "cloud-chamber method" to isolate and determine the mass of a single electron. They did it in a fashion, but the achievement of this remarkable work belongs to one who, here in America, after reading about Thomson and his school, had set out to trap a single electron and actually measure it. One might as well attempt to capture the mote in a sunbeam and weigh it on a grocer's scale.

In the science laboratory of the University of Chicago worked Robert Andrews Millikan, a man about C.T.R.'s age. He had carefully read accounts of the work already done in the Cavendish Laboratory at Cambridge. Then he set to work to construct a new piece of apparatus. It consisted of two brass plates about one-third of an inch apart. In the center of the upper plate he bored a hole the diameter of a needle, and illuminated the space between the plates by a powerful beam of light. He connected the brass plates to a battery which supplied ten thousand volts.

By means of an ordinary commercial atomizer he sprayed oil into the air above the upper plate. These drops of oil were one ten-thousandth of an inch in diameter. Millikan was certain that eventually one single drop of this oil spray would find its way through the tiny hole to the space between the plates. For hours at a time he watched this space through the eyepiece of a powerful microscope. Suddenly he noticed, against the black background of his field of vision, a single neutral droplet of oil, like a glowing four-pointed star, fall gently through that space. Millikan repeated the experiment, and observed the similar behavior of each drop of oil. It took half a minute to make the fall of a fraction of an inch. Reversing the polarity of the plates did not affect its motion.

Now he had to act quickly. He was going to strip an electron from an atom of this neutral oil droplet. Radium could do this.

He held a small tube of radium so that its rays would strike the oil drop. Something happened. The neutral droplet slowed down in its fall. "When this occurred," Millikan knew, "the droplet was no longer neutral; it had lost some of its electrons and become positively charged." By observing the change in speed with which it travelled he could determine how many electrons it had lost. He noticed that the droplet always travelled at definite rates of speed. There was a certain *minimum* speed. The speed would be suddenly doubled, then tripled. "It was easy to see," wrote Millikan, "that the slowest speed was the *result of the loss of one electron*. This proved conclusively that the smallest invisible load which I was able to remove from the droplet was actually one electron and that all electrons consist of exactly the same quantity of negative electricity."

Millikan worked very accurately. His method was fool-proof. By controlling the current he was able to keep his droplets, stripped of electrons, floating between the plate for hours while he left his laboratory to dine or lecture. With the same apparatus he tried another series of experiments, using droplets of mercury, and even droplets of glycerine. These specks of matter were much heavier than the oil, but the same incontrovertible results were obtained.

By means of this electrical balance, thousands of times more sensitive than the most delicate mechanical scale, Millikan had isolated and determined the mass of an electron which agreed closely with the value obtained by Thomson, i.e., eighteen hundred and fifty times less than the mass of a single atom of hydrogen. Some criticized this value. Ehrenhaft of Vienna, for example, worked with tinier drops and reported smaller charges than Millikan had found. But the Austrian's figures were later proven erroneous.

Thomson heard of this remarkable achievement. He did not

wonder that it had taken three years of patient labor to accomplish. It was not at all strange that the electron had eluded man so long. "The population of the earth is a billion and a half," Thomson said. "The smallest number of molecules we can identify with ordinary means is about seven thousand times the population of the earth. In other words, if we had no better test for the existence of a man than we have for that of an electrified molecule we should come to the conclusion that the earth is uninhabited." A clear-cut practical analogy from a fanciful dreamer.

What did all this mean? Just one thing. Matter and electrical energy were one. The electron, a negative particle of electricity, entered into the composition of every atom. But it was only part of each atom. What else composed the structure of the atom? This question was even more difficult to answer.

We must go back once more to the Cavendish Laboratory at the time when Thomson counted among his associates William H. Bragg of crystal fame, Richard T. Glazebrook and William Napier Shaw, who later became assistant directors, Harry F. Reid, American geologist of Johns Hopkins, and Arthur Schuster of Owens College who was to give the first correct explanation of Röntgen's X-rays. It was a select group, which had to be kept small because of the lack of greater facilities. Now Thomson opened the doors of his laboratory to other research students. New ground was about to be broken again in science. In October, 1895, within a few hours of each other came two recruits—John Sealy Townsend from Dublin, and a twenty-four year old boy fresh from the University of New Zealand.

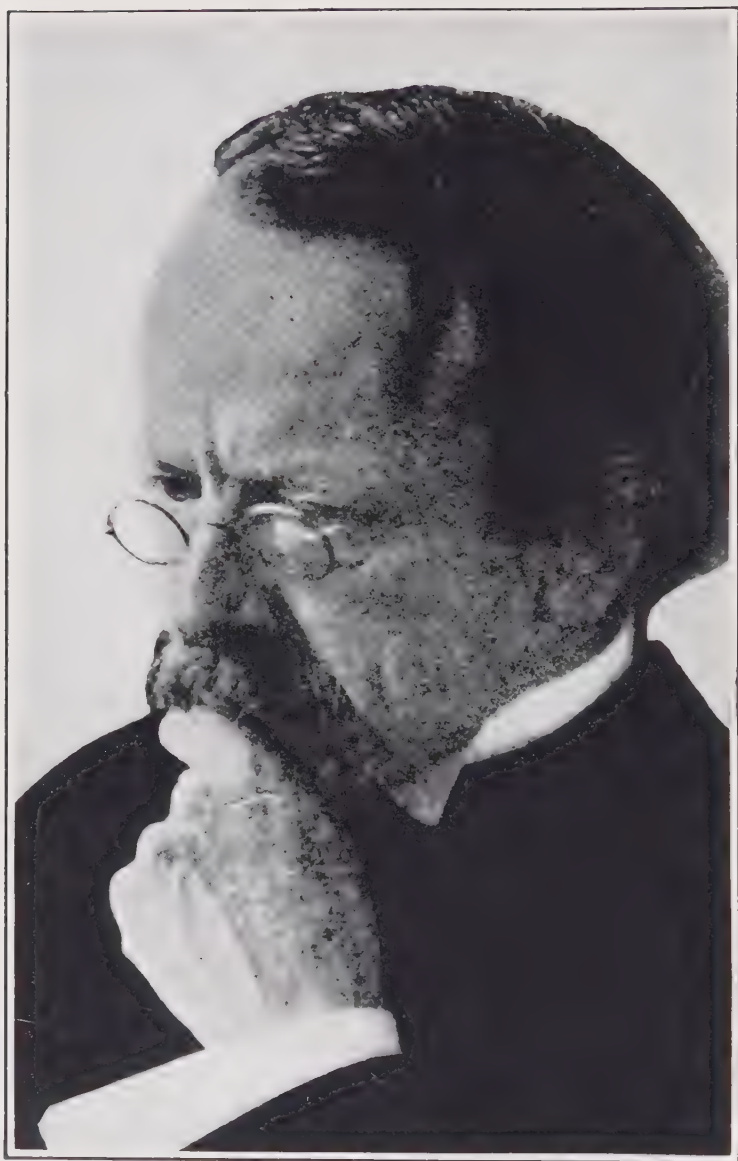
Ernest Rutherford of Nelson, New Zealand, had come a long way. He had heard of this ancient college whose very breath was reverence for pure science. Here honor students from all

over the world fought valiantly for the mastery of nature. Scions of distinguished families came from luxurious palaces to vie with peasant boys from rolling plains and stuffy garrets. Nowhere else in the world could one breathe this sacred atmosphere.

Rutherford, who had received honors in mathematics and science, had been enabled to come to England by the help of a scholarship from home. As he caught the first glimpse of the sacred pile of Trinity College his heart leaped. This temple was the shrine of Newton and Maxwell. Standing before the stained glass windows of the Chapel he vowed to make himself worthy of these masters. Michael Pupin, a decade before, had made that pilgrimage from America. In the forenoon of the day of his arrival, he had seen "a monastic looking procession of serious and thoughtful men in black caps and gowns suddenly change into gay groups of lively youths." The afternoon was reserved for play. But Rutherford was not to be found in the afternoons in white flannel trousers and gay colored blazer. He was to work every minute of the day.

The New Zealander at once caught the spirit of the Master. He found him human, helpful, inspiring. What a wonderful mind he had! He loved, too, Thomson's characteristic smile. And he soon began to feel ecstatic pleasure on hearing the heavy footsteps which every Cavendish man recognized as solely J.J.'s. Among a cluster of brilliant men Rutherford worked here for four years.

Then Thomson was asked to name one of his students to fill the chair of physics at McGill University. J.J. had a splendid group of twenty-five research workers in his laboratory. Blindfolded he could have picked a man among that band without danger of making a mistake. But to him Ernest Rutherford was the brightest jewel. How this man could work! Tirelessly,



JOSEPH JOHN THOMSON

dexterously—with the skilful fingers of a pianist and the imaginative mind of a visionary. Thomson hated to lose this dynamic being, but he realized that at Montreal, in his own laboratory, Rutherford was bound to accomplish wonders. Rutherford, too, was reluctant to leave—there was only one J.J. But he was destined to make the trip to Canada to shed luster on McGill University for almost ten years.

Before Rutherford left the Cavendish Laboratory he had taken active part in the many discussions over the work of Becquerel, Roentgen, and the Curies. Here was a virgin field full of possibilities. He chose it, and began working with uranium and thorium, a kindred element. By 1900, he had already noticed a peculiar phenomenon in connection with the latter substance. It gave off a minute amount of a gas very rich in radioactivity. He carried out precise experiments to determine the nature of the gas and found, to his astonishment, that it was a hitherto unknown substance. He named this gas thorium “emanation.”

Rutherford, like Thomson, surrounded himself with research students. From Oxford University came Frederick Soddy. There were, to be sure, other centers of scientific research nearer home, but Soddy was eager to work with Rutherford. Soddy was only twenty-three, but he had a mind as keen as Rutherford's. These kindred spirits worked together for two years, and towards the end of 1902 they published jointly, in the *Philosophical Magazine*, a new theory of radioactivity.

Atoms of radioactive elements, they declared, were not stable entities. They were constantly changing and withering away. During this breaking down process, positive particles were thrown off by the radioactive elements. Rutherford called these particles *alpha rays*. Atoms of radium, spontaneously and utterly beyond his control, were slowly flying to pieces propelled by an

internal explosion which nature alone could govern. Neither the extreme cold of liquid air nor the intense heat of an electric furnace influenced this disintegration. Heraclitus, the Greek, was right, "Change was everywhere, nothing was stable."

And now, just when Rutherford needed it most, a new instrument was made ready for him by the same William Crookes who had gazed unknowingly at the flight of electrons. This little device, inexpensive, easily manipulated, was a simple toy which showed a world in upheaval. It consisted of a small metal tube, one end of which contained a lens. At the other end was a phosphorescent screen covered with a salt, zinc sulphide. Just in front of the screen, inside the tube, was a minute speck of radium salt on the head of a pin.

After resting his eyes in a dark chamber for fifteen minutes, Rutherford looked through this Spintariscopescope. He saw sudden flashes of light. Every scintillation which appeared on the screen bore testimony to the emission of an alpha particle from the radium salt. Every flash of light reported the breaking down of the tiny universe of a radium atom. He easily counted the number of scintillations—about two every second. He knew the weight of radium salt on that tiny pinhead in the tube. And from these facts Rutherford calculated the speed of the disintegration of radium. In a gram of radium thirty-five billion atoms of radium were disintegrating every second. This meant that radium was losing its activity at the rate of one per cent every twenty-five years. At the end of seventeen hundred years, he calculated, radium would have lost half of its strength. A slow process, yet a definite one. Soddy, back in Europe, was in the meantime collecting alpha particles from disintegrating radium and weighing them. His experiments led to results corroborating Rutherford's results, and afforded convincing evidence of the essential correctness of their data. And incidentally

this data enabled him to deduce values for the weight of an individual atom.

The process of disintegration and ejection of alpha particles took place in several others of the heaviest elements. Uranium, for example, took six billion years for half of it to disappear. Amazing facts backed by careful experiments, and capped by as daring a theory as had ever been expounded. And all this by a man scarcely out of his twenties, working with a boy of twenty-five. The whole accepted structure of chemistry seemed to be standing upon shifting sands! Another established belief—the immutability of atoms—had been dealt a death blow.

Rutherford's fame was spreading. More students came to Montreal. The Old World was making a pilgrimage to the New to sit at the feet of a man who had come out of the Antipodes. The United States, too, was soon represented in the laboratory of Professor Rutherford. Bertram Boltwood came there from Yale University to measure the weight and speed of formation of alpha particles from the disintegration of radium. There was a world of work still left undone. Thomson had discovered that the negative rays given off by radioactive elements were identical with his negative particles of electricity or electrons. Rutherford wondered what the positively charged alpha particles might be. Why did all radioactive substances eject these particles? He knew that alpha particles moved with tremendous speeds and could penetrate thin paper. They could even pass through very thin glass, although the walls of an ordinary tube stopped their flight. He was going to trap these alpha particles, and examine them by means of a spectroscope which could detect one-tenth of a millionth of a gram of a metal.

Rutherford was another Thomson. One who knows him well thus describes him. "He is a man resembling the alpha particle in his local concentration of energy. He is inimical to leisure.

He can arouse enthusiasm in anything short of a cow or a cabinet minister. Frank and genial, he can discuss almost any subject and smoke almost any tobacco."

As a source of alpha particles, Rutherford took some radium emanation. It was not a simple task to construct the apparatus he planned. He broke hundreds of tubes and tried different kinds of glass, until finally he made a double tube, one sealed inside the other. Rutherford filled the inner tube, an extremely thin one, with emanation before sealing it to the outer tube. After two days he examined the space between the tubes, which had been carefully exhausted of all gas. Only alpha particles could penetrate the thin walls of the inner tube and get into this void. Yet what was his astonishment when the spectroscope showed unmistakable evidence of the presence of *helium* gas between the tubes. He tried the experiments a number of times. Yes, it was true! The alpha particles had passed through the thin walls and were identified as atoms of helium. He announced the identity of alpha particles as positively charged atoms of helium. Here was a significant revelation, and it was accepted. The world had learned to believe this man. When Thomson at Cambridge heard of this masterful proof, he shook his massive head, and thought with pride of this human powerhouse. Rutherford's contributions to science were recognized by King George V and he was knighted, as his Master had been ten years before.

Just before the outbreak of the World War thirty different researches were going on at the same time in Thomson's laboratory at Cambridge. Nearly all of them related to the fascinating problem of the structure of the atom. Suddenly the Cavendish Laboratory ceased to be the busy hive of research students fighting a battle against the atomic world. Almost overnight the men scattered to do more pressing government service. The labora-

tory was turned into a factory for the manufacture of pressure gauges, and Thomson and Rutherford devoted themselves to war work. With the ending of hostilities Thomson, now past sixty-two, retired as head of the Cavendish Laboratory to become Master of Trinity College, Cambridge. Rutherford was selected to succeed him. He was ready to perform a research which stands as his crowning achievement.

Ever since Thomson had discovered the electron as part of every atom, Rutherford had pondered over the nature of the rest of the atom. His study of radioactivity had revealed a little. Surely, he thought, there must be in the neutral atom of all elements some positive electricity to counteract the negative electron. Thomson had postulated this theory. Arrhenius, fighting for his ions, had spoken of positively electrified atoms in solution. Even Berzelius, a century before, had introduced the idea of electrically polarized atoms. Rutherford was to attempt to prove the presence of particles of positive electricity in all atoms. It was difficult enough to isolate, photograph and determine the mass of an electron. The positive part of the atom was even more resistant to investigation. But the imaginative mind of Rutherford soon hit upon an ingenious method of attack.

If he was to conquer the inner citadel of the atom he must use projectiles small enough to enter it. Yet his projectiles must be powerful enough to disrupt the most stable thing in the whole universe. The mightiest battering ram ever used by man must be puny in comparison to the energy of the bullet which he must use. He knew all about the alpha particle. He had identified and christened it. He understood its colossal powers. It possessed the greatest individual energy of any particle known to science—seven million electron volts. The mass of this tiny positive particle of helium was eight thousand times as much as that of an electron. It was ejected from radium with the

stupendous velocity of twelve thousand miles per second, a speed which would bring us to the sun, ninety three million miles away, in a little more than two hours. It moved three hundred times faster than a meteor. He was going to shoot this alpha particle through nitrogen gas.

In June, 1919, with the aid of C.T.R.'s camera, Rutherford photographed the path of the alpha particles he shot through nitrogen. The electrons of the nitrogen atoms would have no effect on his alpha particles. Due to the great difference in weight, "an electron would have little more effect on an alpha particle than a fly on a rifle bullet." He expected his alpha particles to pass through the nitrogen undisturbed. The fog tracks of the alpha particles ought to be straight lines. Thousands of the tracks did turn out to be straight. But here in the picture was one which seemed suddenly to have been thrown off its course. The alpha particle, submicroscopic projectile, the tiniest bullet in the world, must have struck something heavy and stable enough to turn the mighty bomb off its direct path. Or, perhaps, the positively charged alpha particle had approached close enough to some massive nucleus, similarly charged, which repelled and deflected it through an angle close to 180° at times. There must be, he concluded, something very solid inside the atom to twist the flight of a projectile with an energy four hundred million times that of a rifle bullet. To be sure, the alpha particle had ploughed its way a distance of more than two inches through tens of thousands of nitrogen atoms before it was deflected.

What was this heavy central core of the atom of nitrogen? Rutherford suspected it might be a group of positively charged hydrogen atoms for he had found them after the bombardment. He was certain there was no other way to explain their presence. With the help of James Chadwick, a young assistant, he con-

tinued to bombard the atoms of other elements. They used sodium and aluminum, two metals, and then a non-metal, phosphorus. In every case positively charged hydrogen atoms were ejected from the nucleus of the atom. The spectroscope had positively revealed hydrogen to them. There was no other conclusion to draw. This positively charged atom of hydrogen, lightest of all the atoms, must be present in the nucleus of all atoms.

Here was the counterpart of the negative electron. This positive charge of electricity was like the electron; it could be deflected by powerful magnets, it obeyed the same laws. The great difference between them lay in their different masses—the positive particles in the nucleus were almost two thousand times as heavy as the electron. A few months later, at the Cardiff meeting of the British Association in Wales, Rutherford christened the new arrival *proton*, just as twenty-three years before Thomson had announced the discovery of the electron.

Here was Rutherford's greatest completed contribution to science. He gave us a new picture of the structure of the atom—an atom resembling the solar system with its massive nucleus of positive electricity around which, at a relatively great distance from this sun, revolved small planetary electrons. The atom was a tiny universe made up of nothing but negative electrons and positive protons.

A few years ago a dinner was given at Cambridge in honor of Joseph John Thomson. Disciples who had passed through his laboratory during the last half century were now spread over the world in every school and laboratory. None of them had forgotten the cherished years of his comradeship and inspiration. A paper was delivered to the Master of Trinity College: "We, the past and present workers in the Cavendish Laboratory,

wish to congratulate you on the completion of your seventieth year. We remember with pride your contributions to science, and especially your pioneer work in the structure of the atom." It was signed by two hundred and thirty men, among whom could be counted the greatest scientific geniuses of our time, including five Nobel Prize winners in science.

Ernest Rutherford, Thomson's most eminent pupil, was present as toastmaster. He read a few of the telegrams of congratulation which poured in. They made a simple, inspiring tribute. From Copenhagen came the voice of Niels Bohr, another Nobel laureate, extolling J.J. for "having opened the gates to a new land." Venerable George Ellery Hale of Mt. Wilson Solar Observatory of California wrote a message of good cheer as he scanned the heavens for new stars. Millikan, measurer of the electron, sent a message expressing the conviction that Thomson's electron would "probably exert a larger influence upon the destinies of the race than any other idea which has appeared since Galileo's time." It was no inflated compliment to link the names of Galileo Galilei and Joseph Thomson.

Thomson has given to the world its knowledge of the smallest entity in the whole universe. This tiniest of all things is omnipresent. It has helped build the atoms, the molecules, the stars. From the simplest atom of hydrogen to the mighty star, bright red Betelgeuse, a hundred billion times larger than our earth, the electron is part of all matter. In all the universe 600,000,000,000,000,000 miles in circumference, the commonest thing is the busy little electron.

There sat its discoverer, still mentally alert, with the same characteristic smile—the same human yet almost god-like J.J. Through the great gathering of eminent scientists and philosophers the spirit of that young, old man was dominant. Suddenly

the voice of the assembly burst forth in the song of the *Jolly Electron*:

There was a jolly electron—alternately bound and
free—
Who toiled and spun from morn to night, no snark so
lithe as he,
And this the burden of his song forever used to be:—
I care for nobody, no, not I, since nobody cares
for me.

Though Crookes at first suspected my presence on this
earth
'Twas J.J. that found me—in spite of my tiny girth.
He measured first the “e by m” of my electric worth:
I love J.J. in a filial way, for he it was gave me birth.

Then Wilson known as C.T.R. his camera brought to
bear,
And snapped me (and the Alphas too) by fog tracks
in the air.
We like that chap! For a camera snap is a proof
beyond compare:
A regular star is C.T.R.—we’d follow him anywhere.

'Twas Johnstone Stoney¹³ invented my new electric
name,
Then Rutherford, and Bohr too, and Moseley brought
me fame.
They guessed (within the atom) my inner and outer
game.
You’ll all agree what they did for me
I’ll do it for them, the same.¹⁴

And as the strains of those verses, sung to the tune of the
Jolly Roger, echoed through that room, the Master still dreamed
of other scientific conquests. He was developing a new method
of chemical analysis by means of “positive rays.” Again he was

doing the impossible—imprisoning on an impalpable balance molecules which have an existence of but the ten-millionth of a second. Upon his photographic plates he located tracks “corresponding to molecules found neither in the heavens above nor the earth beneath—grotesque monsters of the world of molecules as N_3 and H_3 ,” which live and die in a fraction of a second. The world no longer questions the discoveries of this man who trailed the electron to its lair and brought it out into the light.

When the time comes to erect a monument to this man, “perhaps the noblest symbol that could be placed thereon would be e/m .”

XV

MOSELEY

THE WORLD IS MADE OF NINETY-TWO

IT HAS been the fate of some men to accomplish in their youth a work of surpassing importance, and then to have their career suddenly cut short by a great catastrophe. Such is the story of Henry Moseley, whose life work was done in less than four years. Before the world had heard of him, he was gone.

In the summer of 1914, while the English school of scientists was hot on the trail of the mystery of the chemical elements, one of Professor Townsend's students at Oxford stopped to say good-by to him. The boy was to board a steamer that morning for Australia to take part in the forthcoming meetings of the British Association for the Advancement of Science. With him was his mother Amabel, now the wife of William Johnson Sollas, professor of geology at Oxford.

The arrival of mother and son in Australia coincided with England's declaration of war against Germany. Moseley would have enlisted at once, but he had certain engagements to fill. He had just completed an astounding piece of research which threw a flood of light on the inner structure of the atom. Two weeks after Britain's entry into the war, he took part in the great scientific discussion at Melbourne led by Ernest Rutherford, and a week later, at Sydney, read his paper on the nature of the elements.

As soon as the Australian meeting of the British Association was over, Moseley hastened home to offer his services to the government. He could work at home, he was told, in one of

the war research laboratories, but he refused. He wanted active service at the front. So during the madness of those early war days he was granted a commission in the Royal Engineers.

On June 13, 1915, Moseley was already on his way to the front at Gallipoli as signalling officer in the 38th Brigade of the First Army. He had a charm of manner, a frankness and fearlessness, that endeared him to his men and fellow officers in trench and billet. His letters to his mother from the East were full of cheer. He wrote nothing of the hardships and terrors of the campaign in the Dardanelles. Rather he sent her messages of his observations of nature as he rambled over the hills near the trenches. Like his father, he was a keen and observant naturalist. As a boy he had known most every bird and bird's nest in the neighborhood of his home. He had also been greatly interested in prehistoric implements, and on holidays, on the Isle of Wight, he used to search the blue clay deposits with his mother or sister, and found some excellent specimens which are now in the Pitt-Rivers Museum in Oxford. During one vacation he picked up a very beautiful arrowhead in a small cairn in the Shetland Isles. Moseley had been very proud of this specimen and showed it to his friend, Julian Huxley, when he came down from Balliol College to spend his vacation with him. Charles Galton Darwin joined them at times, and the three boys, all of the same age, grandchildren of three famous scientists who had made these very rocks and stones tell weird stories of the birth of the world, were now immersed in a great world struggle.

In less than two months Harry's letters to his mother ceased. From one of his fellow officers came the dreadful news: "Let it suffice to say that your son died the death of a hero, sticking to his post to the last. He was shot through the head, and death must have been instantaneous. In him the brigade has lost a

remarkably capable signalling officer and a good friend; to him his work always came first, and he never let the smallest detail pass unnoticed."

Little did this officer realize the greater tragedy that occurred when young Moseley was stricken at Suvla Bay as he lay telephoning to his division that the Turks, two hundred yards away, were beginning to attack. But there were many who realized the colossal loss. Said Millikan: "In a research which is destined to rank as one of the dozen most brilliant in conception, skilful in execution, and illuminating in results in the history of science, a young man twenty-six years old threw open the windows through which we can glimpse the subatomic world with a definiteness and certainty never dreamed of before. Had the European War had no other result than the snuffing out of this young life, that alone would make it one of the most hideous and most irreparable crimes in history." As Moseley lived so he died, bequeathing in his soldier's will made on the battlefield all his scientific apparatus and private wealth to the Royal Society for the furtherance of scientific research.

When Harry was four years old his father, Henry Nottidge Moseley, professor of comparative anatomy at Oxford, died. He was a very strong man, never fatigued by either physical or mental exertion, but he had lately overworked and began to suffer from cerebral sclerosis. When his end came in 1891, the upbringing and education of the boy was left entirely in the hands of his wonderful mother. So well did she prepare him that at the age of thirteen he entered Eton with a King's scholarship.

His life and experiences at school were those of an ordinary healthy English boy. He early showed his liking for mathematics, and when he went to a boarding school at the age of nine, it was found that he knew the rudiments of algebra,

although he had never been taught them. In the home school room he had sat, presumably writing copies which did not interest him, and instead listening to his two elder sisters being taught the beginnings of algebra, which he found very entertaining. This genius for mathematics was later to aid him in his great research.

After five years at Eton he entered Trinity College, Oxford, with a Millard scholarship in natural science. He had also done brilliantly in the classics; his mind was not lopsided. Harry exhibited the gifts of his distinguished family. His father had such keen intellectual powers that it was said he had only to be put down on a hillside with a piece of string and an old nail and in an hour or two he would have discovered some natural object of surpassing importance. His grandfather, Henry Moseley, had been a celebrated mathematician, physicist and astronomer at Kings College, London. On his mother's side, his grandfather, John Gwyn Jeffreys, had been an eminent oceanographer and authority on shells and mollusks. His elder sister, Mrs. Ludlow Hewitt, distinguished herself at Oxford in biology and contributed a valuable paper on a new subject in science, the rudimentary gill of the crayfish.

Before Harry graduated with honors in natural science, he was dreaming of a career in pure science. He made a visit to Ernest Rutherford at Manchester. This famous teacher saw in him one of those rare examples of a born investigator. He suggested his own first love—radioactivity. Harry was jubilant. He returned home with the thought of this research burning in his mind, and a year later, upon his graduation from Oxford, he proceeded at once to Rutherford's laboratory. Here he soon became so engrossed in his work that he resigned from his lectureship at the University to give every minute of his time to his experiments.

He was now working hard at Manchester. He used to come down to his mother's home of a rare week-end. His mother had bought a piece of land close to the New Forest in southwestern England, and had a little home built, the plans of which were made by Harry when he was eighteen, and accepted as workable by the builder. He took great delight in the new garden around the house, which was simply a piece of heather land, and planned and arranged this garden entirely himself. He planted it with many rare and unusual trees and shrubs. Nothing gave him more enjoyment than to see his garden growing up and doing well. "The only trees which did not succeed," writes his mother from Banbary Road, "were a row of Sophoras, made in Germany, as we said, for the English nurserymen having none in stock had imported them for us. He (Harry) always left me with many garden tasks to carry out in view of improvements."

Moseley had the good fortune to be trained under the guidance of a master experimenter. When Moseley came to him, Rutherford mapped out a definite line of work. First he was to perform some very accurate measurements. He set him the task of finding out the number of electrons emitted during the disintegration of radium, and Moseley lived up to the expectations of his teacher. Before the Royal Society the following year he announced that, on the average, every atom of radium produced but one electron. Sir William Crookes, President of the Society, listened to this clear, fluent speaker and complimented the young man on his simple presentation of so difficult a problem.

Moseley then played with a problem concerning the life of an emanation of actinium, one of the radioactive elements. This period was so short that special, delicate devices had to be constructed to detect it. Together with the Polish scientist, Dr. K. Fajans, now Professor of Chemistry at the University

of Munich, he solved the question. The average life of the emanation was less than one five-hundredth of a second.

The following year, he was busy on another ticklish bit of research. He was trying to determine whether any limit could be set to the strength of the electric charge of an insulated body containing radium. As radium continued to lose negative electrons, it became more and more strongly charged positively. What could be the limit of this positive charge? The difficulties to be overcome were tremendous, but Harry went serenely along as if he were playing some simple game. The radium by losing electrons kept building up a difference of potential in the vacuum tube until it had reached one hundred thousand volts. This charge he was able to increase until the radium emanation withered away and disappeared.

Now news reached the scientific world that Max von Laue of the University of Zürich had discovered a peculiar property of crystals when exposed to X-rays. X-rays, consisting of extremely short waves in the ether (ten thousand times smaller than those of ordinary light), are produced when a stream of electrons falls upon the metal reflector of a Crookes tube. Max von Laue found that pure crystals of salt split up X-rays like light—the minute spaces between the atoms of the crystals acting like a grating and producing an X-ray spectrum. Professor William Henry Bragg and his son, William Lawrence, using this discovery, developed a method which enabled them to determine the inner structure of pure salts. X-rays were allowed to pass through very thin sections of crystals and then photographed. They found that crystals were made up of regularly spaced rows of atoms, (not molecules), about one twenty-millionth of an inch apart. From mathematical calculations, the Braggs made a real pattern of the crystal in three dimensions. Moseley followed closely these experiments of the father



NIELS
BOHR



R. A.
MILLIKAN



ERNEST
RUTHERFORD

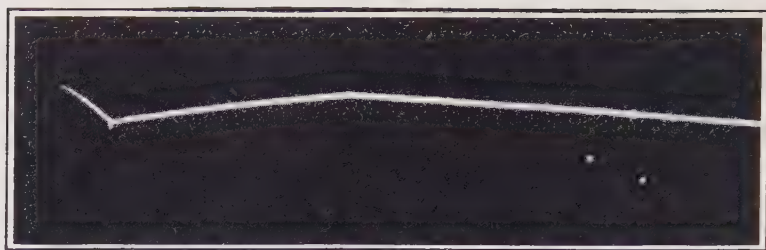


FREDERICK SODDY

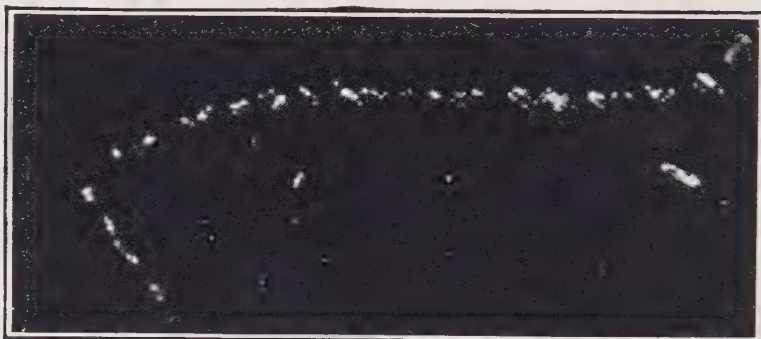


F. W. ASTON

FIVE NOBEL PRIZE WINNERS IN THE
FIELD OF ATOMIC STRUCTURE



FOG TRACK OF AN ALPHA PARTICLE



FOG TRACK OF AN ELECTRON.



FOG TRACKS OF X-RAYS

and son at Leeds. Then he and Darwin, his boyhood chum, photographed the X-rays produced by electrons striking the positively charged platinum plate of a Crookes tube and then passing through a crystal grating. Here was the germ of the classic research which was to bring Moseley, the modern crystal gazer, imperishable fame.

Shortly before Laue's discovery, Rutherford had been led to propound a theory of the nucleus of the atom. He believed that the main mass of the atom was concentrated in a tiny nucleus of positive hydrogen atoms surrounded by enough electrons to make the atom electrically neutral. He had reached this deduction while trying to find the counterpart of the electron in the atom. His delicate experiments on the scattering of alpha particles as they were shot through gases had resulted in the dispersion of these tiny masses. From the angle and intensity of deflection he had calculated the positive charge in the nucleus of the atom. In 1911, with the aid of his students, Geiger and Marsden, he actually determined the number of positive charges in the atoms of gold and other elements and found them to be equal to approximately one-half their atomic weights. The greater the atomic weight of the element, the greater was the positive charge in the nucleus.

Rutherford ventured a prophetic hypothesis. "*The charge in the nucleus of every element,*" he said, "ought to be *proportional to the atomic weight* of the element." Could this guess stand the critical test of experiment?

This was a problem for the most brilliant of his students. He called Moseley into conference. Rutherford was like his old Master at Cambridge. They discussed this research thoroughly, and before Moseley left him a decision had been reached. X-rays were known to be of two kinds. The first was due merely to the stoppage of electrons. The second was sent out from the

anticathode of a Crookes tube and depended upon the metal or metals of which the anticathode was composed. Charles G. Barkla, then of the University of London, had discovered this atomic phenomenon and had determined the length and penetrating power of these rays by absorbing them in very thin sheets of metallic aluminum—a research which earned him the Nobel Prize in 1917. Moseley was to compare the photographs of the X-ray spectra of different elements, and thus help determine the nature of the electric charge in their nuclei.

From the very beginning Moseley was fully aware of the tremendous importance of this piece of research. He told this to his mother. He never wrote to her about it, but would discuss it with her at home. He did not see his mother so often now. He worked in his laboratory day and night. If genius is an infinite capacity for taking pains, as Carlyle believed, then Harry Moseley possessed genius. "His powers of continuous work were extraordinary, and he showed a predilection for turning night into day. It was not unusual for an early arrival at the laboratory to meet Moseley leaving after about fifteen hours of continuous and solitary work through the night. This trait he inherited from his father no doubt." Here was an outstanding example of a man working with religious fervor, thinking of no recompense save the joy of wholehearted work for the love of pure science.

Moseley fixed a metal plate at the anticathode of a Crookes tube. This metal acted as target for a stream of electrons sent out from the cathode, or negative pole. When the metal was thus excited it emitted its characteristic X-rays. These rays were then allowed to fall as a narrow beam on a crystal mounted on the table of a spectroscope. The reflected rays were then photographed. Moseley discarded Barkla's method for deter-

mining the nature of the X-rays and perfected this new method of photographing X-ray spectra.

Now he was ready to repeat this procedure with as many elements as could be treated in this manner. Above aluminum in the Periodic Table were twelve elements which could not be adapted to this method of attack. He started with the thirteenth element, the metal aluminum. He invented an ingenious device to speed up his experimental observations. He arranged a series of plates of the different elements on a movable platform in the Crookes tube so that every one of these elements could easily be made the anticathode. This piece of apparatus delighted him. He was like a boy amusing himself with some mechanical contraption of his own invention.

Formidable problems presented themselves at every turn. In some cases the rays were so easily absorbed by the glass that Moseley had to devise a window in the glass tube thin enough for the rays to pass through. It was not an easy task. He built a window in the glass wall of the tube and covered it with gold-beater's skin, a very thin membrane of the large intestine of an ox, but the extremely high vacuum in the tube resulted in oft-repeated ruptures of the window. It was a delicate and tedious job to keep renewing the window and re-exhausting the tube. But Moseley had the patience of his ancestors, and went quietly about making the many annoying changes.

When he imagined he had overcome the most difficult part of his experiment another problem presented itself. To avoid absorption of the X-rays, the whole photographic apparatus, including crystal and spectroscope, had to be enclosed in a glass vessel exhausted of air. Again, with characteristic energy, he accomplished an almost impossible job.

He worked with such breathless activity that within six months he had examined the X-ray spectra of thirty-eight elements,

from aluminum to gold. Moseley studied the results of his measurements. Different elements gave rise to X-rays of different wave lengths. He confirmed a definite relationship—the heavier the element the shorter and more penetrating the X-rays produced. He arranged all his figures on graph paper. He plotted the numbers of the elements, representing their position in Mendeléeff's table, against the inverse square roots of the vibration frequencies of their X-rays. The elements actually arranged themselves on a straight line in the exact order of their atomic weights.

Moseley went back to Oxford now to live nearer his mother. Professor Townsend gave him a private room in his laboratory where he could work quietly and independently. Here he completed his last research in science. What could these figures and graphs mean? Moseley heard the weak whisper of Nature yielding another of her secrets. The whisper gradually became louder. A strange story was told to young Moseley: "There is in the atom a fundamental quantity which increases by regular steps as we pass from each element to the next. This quantity can only be the charge on the central positive nucleus."

In 1912, at the age of twenty-six, Moseley published his results—he had discovered the *Law of Atomic Numbers*. He prepared a new Table of the Elements more fundamental than that of his Russian predecessor. He gave the world an infallible road map of all the elements of the universe—a chart based, not on atomic weights, but on atomic numbers. Mendeléeff's romantic blue-prints had served science for fifty years. Now a new and more enduring structure was reared, fashioned by the cunning brain of a youth.

The first element in his Table was hydrogen, with an atomic number of one; uranium, with an atomic number of 92, was the last element. For the first time, a scientific limit to the number

of building blocks of the universe was set. There could be no other elements besides these ninety-two, said Moseley. It was an astounding declaration. More than seventy elements had been announced during the last generation to fill sixteen gaps in Mendeléeff's Table. Moseley's work showed that almost all of them were spurious discoveries. It definitely settled the claims of men who had "discovered" new elements. Ogawa, a Japanese, had announced *nipponium* as the missing element eka-manganese of the Russian. Ramsay had disproved its reality—it had no room in Moseley's list of elements. Coronium, nebulium, cassiopeium and asterium, "found" in the spectra of the heavenly bodies and placed in Mendeléeff's Table between hydrogen and lithium, were definitely thrown out as nonexistent. There were no places for these so-called elements in Moseley's List.

His Table of Atomic Numbers brought a new harmony into the classification of the elements. It helped determine the proper placing of a number of elements which Mendeléeff's Table could not explain. He found the atomic number of potassium to be 19, while that of argon was 18, even though their accepted atomic weights called for the reverse order. The positions of cobalt and nickel, and iodine and tellurium, were similarly corrected. The discrepancies of Mendeléeff's Table had been ignored for the sake of harmony. Atomic numbers were immensely more fundamental. They were absolutely trustworthy; not an error could be detected.

When the news of Moseley's discovery reached France, Professor Georges Urbain of the University of Paris rushed to Oxford to meet this man. Urbain, sculptor, musician and eminent authority on rare elements, was baffled by a number of elements found in certain Scandinavian ores, in the sands of North Carolina, and the igneous granite of the Ural Mountains.

Between the elements barium and tantalum were fifteen others so closely allied in properties that it was extremely difficult to separate them completely. These fifteen elements were the "rare earths." Mendeléeff had been confronted by them when he arranged his Periodic Table. He admitted the "position of the rare earths to be one of the most difficult problems offered to the Periodic Law." He could find no place for them in his list of the elements.

No one had found a way to clarify this forbidding group of mysteries—lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutecium. Crookes had expressed the situation confronting chemists rather pessimistically: "The rare earths perplex us in our researches, baffle us in our speculations, and haunt us in our very dreams. They stretch like an unknown sea before us, mocking, mystifying, and murmuring strange revelations and possibilities."

Moseley's Table of Atomic Numbers had places for all of these fifteen elements. They fitted beautifully into spaces 57 through 71. His work on the X-ray spectra of the elements had settled once and for all time the position and number of the rare earths. This in itself was a remarkable achievement.

Perhaps Moseley could help unravel the mess of the rare earths with his new method of analysis. Urbain handed the young Englishman an ore containing an unknown number of the rare earths mixed together in minute amounts. "Tell me," said Urbain, "what elements are present." Moseley did not keep him waiting long. His mystic crystal was at his side. He went through some strange, dexterous movements with his spectroscope, followed by short rapid calculations on paper. Turning to the French savant, Moseley told him the complete story of the rare earths which had taken Urbain months of laborious

analytical operations to find out for himself. Erbium, thulium, ytterbium and lutecium, of atomic numbers 68, 69, 70, and 71, were present, but the element corresponding to 61 was absent.

Urbain was astounded! He put another question to this miracle boy. "Can you tell me the relative *amounts* of the rare earths which are present in this sample?" Urbain felt that perhaps here Moseley might fail. But the Oxford scientist was equal to the task. Urbain was dumbfounded. He returned to France, marvelling at the brilliancy of such a lad. When, a year later, Professor Urbain received Rutherford's letter notifying him of the death of Moseley, the French scientist recalled his memorable visit. "I had been very much surprised when I visited him at Oxford to find such a very young man capable of accomplishing such a remarkable piece of work. The law of Moseley confirmed in a few days the conclusions of my efforts of twenty years of patient work."

In Moseley's Table were gaps for six ¹⁵ missing elements with atomic numbers of 43, 61, 72, 75, 85, and 87. Since Mendeléeff's death not a single one of these elements had been discovered. Soon after the appearance of Moseley's work, however, four of these gaps were filled. Moseley had worked out the X-ray spectra of these hidden elements and prophesied that "They should not be difficult to find." His predictions were fulfilled, for others followed his ingenious line of attack. Within less than ten years, Professor George Hevesy and Dr. Coster, working in the laboratory of Dr. Bohr in Copenhagen, discovered *hafnium*, element No. 72, in an ore of zirconium, which very closely resembled it. One of the first specimens of this new element to be isolated may be found in the American Museum of Natural History. It is not an extremely rare element; cyrtolite, an ore found near New York contains as much as five per cent of hafnium. It constitutes one part in 100,000 of

the crust of the earth, yet it had remained hidden so long because of its close resemblance to other elements of the rare earths.

Then on June 15, 1925, Dr. Walter Noddack and Dr. Ida Tacke of Berlin announced *masurium* and *rhenium*, missing elements Nos. 43 and 75, likewise brought to light by the X-ray spectrum analysis of Moseley. Element 61, probably present in the earth to the extent of not more than one part in a million million, defied detection until 1926, when Professor B. Smith Hopkins and his associates at the University of Illinois, using the same method, added it, as *illinium*, to the list of the elements. This was the second element discovered by an American. Twenty years before, Bertram B. Boltwood, who died by his own hand on August 15, 1927, during a period of despondency, had given us *ionium*, isotope of thorium, parent of radium.

To-day, thanks to Moseley's X-ray spectroscopy, there remain but two ¹⁶ elements, 85 and 87, to be unearthed. Element 85, a radioactive member of the halogens, should be a solid almost as heavy as iron, insoluble in water, and should melt at the same temperature as tin. Element 87 should resemble the alkali metals and have an atomic weight about 224.

When Mendeléeff announced the Periodic Table of the Elements, he frankly stated, "It had been evolved independently of any conception as to the nature of the elements. It does not in the least originate in the idea of a unique matter and it has no historical connection with that relic of the torments of classical thought." He was alluding to the ancient idea of the unity of all matter. Plato had said "Matter is one." Sporadically, this idea of a primordial substance from which everything else originated had been enunciated by philosophers and pseudo-scientists. The Monists, a band of mystics far away from laboratories, talked of the unity of matter, and of the

evolution of the sex-linked elements from some queer ethereal substance. The world paid little attention to their abstract conclusions.

Then, in 1815, there was printed in the *Annals of Philosophy* a paper in which the writer suggested that the *protyle* of the ancients was really hydrogen. The author had calculated the atomic weights of a number of elements and had found them to be whole numbers, multiples of the atomic weight of hydrogen. Thus he listed the atomic weights of zinc, chlorine and potassium as 32, 36 and 40. When he was confronted with a number of elements whose atomic weights were far from integers, he considered the accepted weights erroneous, and declared that the future, with improved methods of analysis, would prove the atomic weights of these elements also to be whole numbers.

Had the author of this idea been Berzelius, he might have created more than a slight ripple. But the anonymous writer proved to be a young English physician, William Prout. His theory that all the elements were formed by various unknown condensations of hydrogen was not taken seriously. The great mass of facts of chemical analysis was against Prout. He himself had done very little accurate determining of atomic weights, but used the data of others, especially those results which fitted his theory.

Prout's theory acted temporarily as a ferment. Berzelius, and later the eminent Belgian chemist, Jean Servais Stas, carried out some extremely accurate atomic weight measurements. This search of the fourth decimal place of atomic weights brought to light many cases of atomic weights which were unmistakably far away from whole numbers. "I have arrived at the absolute conviction," declared Stas, "that the law of Prout is nothing but an illusion, a mere speculation definitely contra-

dicted by experience." The world of chemistry settled back again and forgot Prout and his protyle. Prout returned to his practice of medicine in London. He made another bid for fame a few years later when he announced the discovery and importance of hydrochloric acid in the gastric juice, and then for nearly a century the name of Prout remained forgotten.

Moseley's epochal work on atomic numbers suddenly brought Prout's theory back from the limbo of the past. Perhaps, after all, the idea of the oneness of the elements was not all twaddle. Had not J. J. Thomson shown the electron to be common to all elements? And Rutherford had proven beyond the shadow of a doubt that charged hydrogen atoms were present in the nuclei of all the elements. The great harvest of experimentation of the last fifteen years made it appear almost certain that all the elements were closely related. And now Moseley peeped into the kernel of the atoms and confirmed Rutherford's assumption of the number of protons, or positively charged hydrogen atoms, inside these different atoms.

Prout's conclusions seemed more plausible now. "If the views we have ventured to advance be correct," Prout had written, "we may consider the protyle of the ancients to be realized in hydrogen." Surely all evidence pointed to the presence of hydrogen in the nuclei of all atoms. But there was still a great barrier to the acceptance of this belief. If all the atoms were composed of condensations or multiples of hydrogen, then every element should have an atomic weight equal to some perfect integer, since the atomic weight of hydrogen was one. There could be no place for fractional atomic weights. How could one explain away the atomic weight of chlorine, known to be 35.46, or of lead, fixed at 207.2? Surely these fractional atomic weights could not be the result of experimental errors.

What a powerful weapon could be forged by a clear scientific

explanation of the apparent inconsistencies of Prout's theory. Pregnant doubts and questions had already been raised. Crookes, in 1886, addressing the British Association at Birmingham, had made a bold and original statement. "I conceive that when we say the atomic weight of calcium is 40, we really explain the fact, while the *majority* of calcium atoms have an actual atomic weight of 40, there are not a few which are represented by 39 or 41, a less number by 38 or 42, and so on."

It was an audacious speculation and coming from one of the most eminent scientists of England, it had to be seriously considered. Could it really be possible that Dalton was wrong—that all the atoms of the same element were not alike in weight, although similar in properties? Was it really true that what chemists for a hundred years had considered the unchangeable atomic weights of the elements were only the *average* relative weights of different atoms? Lavoisier had said, "An element is a body in which no changes cause a diminution in weight." Was he really in error?

Paul Schutzenberger's study of the rare earths during the close of his life led him to recognize the possibility of different atoms of the same element. Curie's radium and radioactivity provoked more doubts and misgivings. The discovery of *ionium*, identical in chemical properties with thorium and almost similar to it in weight, had for a long time defied the labors of chemists. The following year *mesothorium I* was isolated and found to be chemically the same as radium, but differing from it slightly in weight. Emanations and other radioactive elements seemed to lend proof to the speculations of Crookes. Perhaps atomic weights were really averages of atoms whose weights were actually whole numbers. Ramsay declared that the existence of such a large number of elements with atomic weights very nearly whole numbers, was not an accident. The

chances were a billion to one that this was fortuitous, he said. By 1910, many level-headed, serious-minded researchers began to whisper the thoughts of Crookes. Frederick Soddy, co-author with Rutherford of the revolutionary theory of radium disintegration, spoke out boldly in favor of Crookes' idea of mixtures of atoms.

At the British Association meeting in Birmingham the year before the opening of the World War, a paper was presented on the homogeneity of neon—there were some doubts as to whether its atomic weight was constant. Soddy, too, standing in the forefront of the new battle, started a great discussion. He had found two samples of a radioactive element with identical physical and chemical properties yet differing in atomic weights. The late Theodore W. Richards, the only American to receive the Nobel Prize in chemistry, had also investigated the subject of changing atomic weights and found ordinary lead to have an atomic weight of 207.20, while that of lead from a radioactive uranium ore from Norway was 206.05. No one could doubt these figures; Richards was the most accurate investigator of atomic weights of his generation.

Soddy came out firmly for his belief in the existence of the same elements having different atomic weights. He had the boldness to give a name to such elements. *Isotopes*—elements in equal places—was the word he coined. What an upheaval this created. What was left of chemistry and all its pretty theories? Was it all a house of sand? In 1897, on the discovery of radium, Professor Runge of Göttingen had cried out, "Nature is getting more and more disorderly every day." What would he have said now? Every time a scientist dug into the foundations of chemistry another rotten, unsafe timber was discovered!

Would not scientists leave some things alone for a while and rest satisfied with the existing structure? It did not appear so.

Men scratched their heads and vexed the elements once more. Chemists were afraid to accept these disclosures. Had not the whole scientific world been taught for more than a century that elements had immutable atomic weights? Richards, one of the world's most accurate experimenters on atomic weights, had called them the "most significant set of constants in the universe." Scientists had believed all atoms of the same element, regardless of source or method of preparation, had fixed atomic weights. If the atomic weight of the element was not fixed, then the whole structure of chemical calculations was only a house of straw!

Was this all just a fabrication? Or was it a clue to the interpretation of the fractional atomic weights of chlorine, lead and neon? Perhaps chlorine, which chemists knew as a simple element, was in reality a mixture of isotopes, each of which possessed atomic weights of whole numbers. When mixed in less than identical amounts, these isotopes would yield a gas with an *average* atomic weight of 35.46. Was this the answer to the inconsistencies of Prout's Theory? Was the death knell of another dogma of chemistry to be heard?

The world again turned to the Cavendish Laboratory for the final answer. New methods of attack had to be devised. Here was the place for radical experiments. At about this time, J. J. Thomson and his "saints of Cambridge" were developing their "positive ray analysis." In this laboratory another of Thomson's brilliant students was at work on this perplexing problem. Francis William Aston came to Cambridge at about the same time that Moseley reached Rutherford in Manchester. The name of Aston had been heard at Cambridge long ago when Newton walked its halls. This Aston was descended from the distinguished family which held the Manor of Tixall in Staffordshire from 1500. Newton had written to a Francis Aston regarding

the transmutation of lead into gold. This new Aston was immersed in a problem of modern alchemy—just as baffling as that of his ancestor. He was to solve the riddle of the isotopes.

“Positive rays” were first clearly described in 1886 by E. Goldstein. He obtained these rays by introducing a small quantity of gas in a Crookes tube containing a perforated cathode. Besides the usual cathode rays there formed, behind the perforated cathode, a stream of positively charged particles. Thomson realized that this stream was composed of nothing else but positively charged atoms of the gas, that is, of atoms which had lost electrons and had become ions.

The great English scientist saw in these positive rays a possible vindication of Soddy’s isotopes with which he had just ruffled the chemical world. He argued that if these ions came from atoms of the same element having different atomic weights, then some means could be found to separate the element into its various isotopes. A powerful electro-magnetic field could sort them out very neatly since the lighter ions would be deflected most.

Aston mastered this new approach to an extremely delicate analysis of the chemical elements and developed it with surprising accuracy. A narrow beam of positive rays was passed into an electro-magnetic field which bent the stream of ions. This deflected beam of rays was then photographed on a sensitized plate. If the stream of ions was composed of atoms of equal mass only one band of light appeared on the plate. Positive rays consisting of atoms of different masses, however, were split into an electric spectrum, the number of bands depending upon the number of isotopes. Even the relative proportion of the isotopes could be determined from the size and darkness of the bands on Aston’s “mass spectrograph.”

Aston began the examination of those elements whose atomic

weights were not integers. He worked first with neon. By November, 1919, definite proof of the existence of two isotopes of the gas neon was established. He had found neon to be a mixture of 90% of neon with atomic weight of 20, and 10% neon, atomic weight 22—hence its accepted fractional weight of 20.2. Here was the first conclusive proof of the existence of isotopes, and the explanation of fractional atomic weights.

A few weeks later the occurrence of the six isotopes of mercury was similarly proven when W. D. Harkins and his students fractionally distilled mercury vapor and separated it into six isotopes. Here was another startling demonstration. In laboratories all over the world scientists followed the lead of Aston and his Master. Rapid progress was made the following year. By March the isotopes of argon, krypton and xenon were sorted out. By July came indisputable proof of the existence of isotopes of boron, silicon, bromine, sulphur, phosphorus and arsenic. Then in December of that year Arthur Jeffrey Dempster, a Canadian working at the University of Chicago, announced his separation of the three isotopes of magnesium.

The proof was overwhelming. Ingenious schemes were invented. Brönsted and Hevesy evaporated liquid chlorine and successfully isolated a minute volume of its isotopes. Professor W. D. Harkins of the University of Chicago played with a series of porous clay pipes, ten feet long, through which, by a process of diffusion, he separated from a ton of HCl, lighter chlorine atoms from heavier ones, the lighter atoms passing through fastest. It was a long, slow, tedious process which took more than ten years. Chlorine was found to consist of two isotopes of atomic weights 35 and 37, so mixed as to give a mean value of 35.46. Elements with integer atomic weights, like hydrogen, helium, nitrogen and fluorine, were found to have no isotopes. The evidence kept mounting. There was no question of the

atomic weights of the elements being whole numbers. In 1922 Aston received the Nobel Prize for this epochal work.

The Unitary Theory of Prout began to be taken seriously. Scientists were arguing upon solid ground. The evidence was conclusive. Moseley had shown the way by determining the exact number of protons in the nuclei of atoms. Rutherford had proven the existence of nothing but hydrogen and helium in these nuclei. And now Aston and his followers presented convincing evidence of the presence of isotopes, all of which had atomic weights of whole numbers. The overthrow of the old conception of the Daltonian atom was complete, and Aston declared, "Let us fix the word element precisely now and for the future, as meaning a substance with definite chemical and spectroscopic properties which may or may not be a mixture of isotopes." In other words, he associated it exclusively with the conception of atomic numbers.

Moseley had builded better than he knew. It is hard to say what this youthful genius might have accomplished had he lived the normal span of life. Had not that Turkish bullet cut him down in the fullness of his powers at Gallipoli, Moseley would undoubtedly have contributed to the great chemical harvest of the last fifteen years. It is safe, however, to say that he could never have outdone his greatest research—the discovery of the Law of Atomic Numbers which solved the riddle of the Periodic Table and the intimate relationship of all the elements.

The beat of the harp is broken, the heart of the gleeman is
fain

To call him back from the grave and rebuild the shattered brain
Of Moseley dead in the trenches, Harry Moseley dead by the sea,
Balder slain by the blindman there in Gallipoli.



HENRY G. J. MOSELEY

(through the kindness of his mother, Mrs. Annabel Nevill Sollas)

Beyond the violet seek him, for there in the dark he dwells,
Holding the crystal lattice to cast the shadow that tells
How the heart of the atom thickens, ready to burst into flower,
Loosing the bands of Orion with heavenly heat and power.
He numbers the charge on the center for each of the elements
That we named for gods and demons, colors and tastes and
 scents,
And he hears the hum of the lead that burned through his brain
 like fire
Change to the hum of an engine, the song of the sun-grain choir.

Now, if they slay the dreamers and the riches the dreamers gave,
They shall get them back to the benches and be as the galley
 slaves.¹⁷

THE NINETY-TWO CHEMICAL ELEMENTS

At. No.	Element	Sym- bol	Atomic Weight	At. No.	Element	Sym- bol	Atomic Weight
1	Hydrogen.....	H	1.0078	47	Silver.....	Ag	107.88
2	Helium.....	He	4.002	48	Cadmium.....	Cd	112.41
3	Lithium.....	Li	6.940	49	Indium.....	In	114.8
4	Beryllium.....	Be	9.02	50	Tin.....	Sn	118.70
5	Boron.....	B	10.82	51	Antimony.....	Sb	121.77
6	Carbon.....	C	12.000	52	Tellurium.....	Te	127.5
7	Nitrogen.....	N	14.003	53	Iodine.....	I	126.93
8	Oxygen.....	O	16.000	54	Xenon.....	Xe	130.2
9	Fluorine.....	F	19.00	55	Cesium.....	Cs	132.81
10	Neon.....	Ne	20.183	56	Barium.....	Ba	137.36
11	Sodium.....	Na	22.997	57	Lanthanum.....	La	138.90
12	Magnesium.....	Mg	24.32	58	Cerium.....	Ce	140.13
13	Aluminum.....	Al	26.97	59	Praseodymium.....	Pr	140.92
14	Silicon.....	Si	28.06	60	Neodymium.....	Nd	144.27
15	Phosphorus.....	P	31.02	61	Illinium.....	Il	?
16	Sulfur.....	S	32.06	62	Samarium.....	Sm	150.43
17	Chlorine.....	Cl	35.457	63	Europium.....	Eu	152.0
18	Argon.....	A	39.94	64	Gadolinium.....	Gd	157.26
19	Potassium.....	K	39.10	65	Terbium.....	Tb	159.2
20	Calcium.....	Ca	40.07	66	Dysprosium.....	Dy	162.46
21	Scandium.....	Sc	45.10	67	Holmium.....	Ho	163.5
22	Titanium.....	Ti	47.90	68	Erbium.....	Er	167.64
23	Vanadium.....	V	50.96	69	Thulium.....	Tm	169.4
24	Chromium.....	Cr	52.01	70	Ytterbium.....	Yb	173.6
25	Manganese.....	Mn	54.93	71	Lutecium.....	Lu	175.0
26	Iron.....	Fe	55.84	72	Hafnium.....	Hf	178.6
27	Cobalt.....	Co	58.94	73	Tantalum.....	Ta	181.5
28	Nickel.....	Ni	58.69	74	Tungsten.....	W	184.0
29	Copper.....	Cu	63.57	75	Rhenium.....	Re	188.71
30	Zinc.....	Zn	65.38	76	Osmium.....	Os	190.8
31	Gallium.....	Ga	69.72	77	Iridium.....	Ir	193.1
32	Germanium.....	Ge	72.60	78	Platinum.....	Pt	195.23
33	Arsenic.....	As	74.96	79	Gold.....	Au	197.2
34	Selenium.....	Se	79.2	80	Mercury.....	Hg	200.61
35	Bromine.....	Br	79.916	81	Thallium.....	Tl	204.39
36	Krypton.....	Kr	82.9	82	Lead.....	Pb	207.22
37	Rubidium.....	Rb	85.44	83	Bismuth.....	Bi	209.00
38	Strontium.....	Sr	87.63	84	Polonium.....	Po	210.0
39	Yttrium.....	Y	88.92	85			
40	Zirconium.....	Zr	91.22	86	Radon.....	Rn	222
41	Colombium.....	Cb	93.1	87			
42	Molybdenum.....	Mo	96.0	88	Radium.....	Ra	225.97
43	Masurium.....	Ma	?	89	Actinium.....	Ac	?
44	Ruthenium.....	Ru	101.7	90	Thorium.....	Th	232.12
45	Rhodium.....	Rh	102.91	91	Protoactinium.....	Pa	?
46	Palladium.....	Pd	106.7	92	Uranium.....	U	238.14

XVI

LANGMUIR

VISIONS OF DISASTER OR THE MILLENNIUM

MOSELEY had just been born when another lad six years old was growing up in Brooklyn, New York. Unlike the English boy, he could pride himself on no scientific forbears. His grandfather was a minister who had emigrated from Scotland to Canada and then brought his family to Connecticut. On his mother's side, too, there seems to have been no hereditary promise of the scientific wizardry which was to develop in this boy.

As a child, Langmuir asked many simple questions about the world in which he lived even as Clerk-Maxwell, at three, kept insisting: "Show me how it does." "Why does water turn to ice?" "Why does water boil in a kettle?" "Why does rain fall?" were some of the questions his parents kept answering. He also bombarded his brother Arthur, who was studying chemistry, with more queries, and when Irving was only nine they built a small workshop in the cellar of their home.

From an early age he began to store up in his active mind a vast mass of knowledge about the physical forces around him. He was constantly building things and tearing them apart. He was sent to a public elementary school in Brooklyn, but did not relish the classroom. He preferred to tinker about in his own workshop or pester his three-year-old brother Dean with problems in arithmetic.

Arthur had now graduated from Columbia College and was planning to continue his science studies at the University of

Heidelberg. His parents decided to remain near Arthur while he was abroad, and, at the age of eleven, Irving was taken to Paris. And while Arthur was doing research in chemistry, Irving spent three years in a Paris boarding school under French tutors. He looked forward to the occasional visits of Arthur, and would listen breathlessly to his tales of research. Irving was only twelve, yet he wanted his own laboratory, and with his brother's aid he built a small one adjoining his room. Here he remained for hours at a time working out the many alluring experiments described in an old textbook he had bought.

The brothers were great pals. On one occasion Arthur took Irving mountain-climbing in Switzerland, and Irving became so enthusiastic over this sport that he wanted to climb everything in sight. The dangers, however, were such that his mother dared not let him go alone for Arthur had to return to the university. Irving pleaded with his father and finally received permission on condition that he would follow certain rules. He was to stay on a distinct trail, use the same trail going and returning, and make certain of returning at six o'clock by allowing as much time for descending as for ascending. Besides, he had to make sketches, maps and notes of the trails before starting. In this way the boy climbed several mountains about seven thousand feet high, often requiring several days of repeated effort before he could discover a route that led to the top. Such was the careful training his father gave him, which was to stand him in good stead years later both in his life-long hobby of mountain-climbing and in his scientific adventures.

The Langmuirs spent three years in Europe. Arthur successfully completed his studies at Heidelberg, and in the fall of 1895 they sailed for the United States, but not before Irving had attended the public funeral of Pasteur in Paris—a scene he never forgot. At fourteen, he entered the Chestnut Hill Academy

in Philadelphia under Dr. Reid. He knew all the chemistry they taught here and more. At this time he came across a book on calculus, became interested in the subject and at the end of but six weeks mastered it. "It was easy," he told Arthur.

The next year he was in Brooklyn again, attending Pratt Institute where his brother was now teaching chemistry. At eighteen he matriculated in the Columbia School of Mines, from which he received the degree of metallurgical engineer, and then left for Germany to do post-graduate work under Professor Nernst at Göttingen—the University made famous by Woehler.

Three years later, Langmuir returned a Doctor of Philosophy to teach chemistry at Stevens Institute in Hoboken. He remained here until 1909. That summer he made a visit to the Research Laboratory of the General Electric Company at Schenectady which had been established eight years before in a small shed-like structure. He planned to spend his ten weeks' vacation doing research work.

In charge of the Research Laboratory was Dr. Willis R. Whitney, former President of the American Chemical Society and a pioneer in the development of a new type of industrial research. He was an unusual leader. Instead of assigning him some definite piece of research, this mold of genius suggested that the young teacher spend a few days watching the staff of researchers at work. Langmuir was fascinated as he went from room to room and problem to problem talking to the men who were reaching into the unknown. Gulliver saw no stranger sights at the storied Academy of Lagado than Langmuir witnessed here. Before him were men peering reverently into the mysteries of science under the guidance of a tall, simple, hearty philosopher, master over men and matter.

One problem in particular attracted him. It was baffling a

number of the research workers. They were trying to make a tungsten wire which would not break so easily in an electric light bulb. Hundreds of samples of this wire had already been prepared, but only three of them showed no weakness. Most of the wires were short-lived, once an electric current was passed through them.

He went to Whitney and asked to be assigned to this piece of research. He wanted to investigate the behavior of these imperfect wires when heated to incandescence in evacuated bulbs. Why did only three wires behave so perfectly? What was wrong with the rest of the samples? Langmuir saw the invisible trouble-makers before he began to investigate. He had an idea that the weakness lay in certain gases which they had absorbed.

Whitney agreed and placed the equipment of the General Electric Company and its entire staff of research workers at his disposal. He somehow felt that this young school-teacher was made of uncommon stuff. All a-tingle, Langmuir set to work immediately. What a far cry, he mused, from the chemical laboratory of his boyhood days. What a difference, even, from the laboratory of the University of Göttingen. Here was, in truth, a citadel—a sanctuary of science.

Whitney dropped in occasionally to watch him. Years later he recalled those first few weeks. "There is something in Langmuir's work that suggests by sharp contrast an oriental crystal-gazer seated idly before a transparent globe and trying to read the future. In my picture an equally transparent and more vacuous globe takes the place of the conventional crystal sphere. It is a lamp bulb, a real light source. Langmuir boldly takes it in his hand, not as some apathetic or ascetic Yogi, but more like a healthy boy analyzing a new toy. There might have been nothing in that vacuum, but he was driven by insatiable curiosity to investigate and learn for himself."

Langmuir expected to find a small volume of gas issuing from the heated wires in the glass bulbs. But what astonished him almost beyond belief was the tremendous quantities of gas given off by the hot tungsten wires. He was a prodigious reader and kept in touch with the advance of science in the great research laboratories of the world. He remembered how J. J. Thomson had mentioned the enormous power which some metals possessed of emitting gases. But his tungsten wires when heated gave off more than seven thousand times their own volume of gases.

His summer vacation had rushed by, and Langmuir must return to the comparative monotony of the classroom at Stevens. He had not discovered the cause of emission of the tremendous volumes of gases, but he suspected the reason. The glass bulb of the incandescent lamp, he surmised, gave off water vapor which, reacting with the glowing tungsten wire, produced immense volumes of hydrogen gas. This chemical action weakened the tungsten wire and shortened its life in the lamp.

Dr. Whitney had watched Langmuir at work. He marvelled at his dexterity and the keenness of his mind. What an intuitive ability he possessed to go to the heart of a problem, discarding quickly and unhesitatingly the mass of non-essentials! His powers of reasoning from observed effects to probable causes were almost uncanny. He could, even before he had touched a piece of apparatus, visualize results.

It would be a pity to lose this man who could "hold his theories with a light hand and keep a firm grip on his facts." Whitney made Langmuir a tempting offer to stay with him as a member of the research staff. His place in the classroom could be filled by some other less gifted instructor. Langmuir hesitated at first. Would it be fair, he asked Whitney, to spend the money of an industrial organization like the General Elec-

tric Company for purely scientific work which might never lead to any practical application? "It is not necessary for your work to lead anywhere," replied Whitney. Langmuir then and there made up his mind—he would remain in Schenectady.

It was a great day for Langmuir. He decided to continue his work on the incandescent lamp. Dr. Whitney believed with every other lamp engineer in the country that the solution of the lamp problem lay in obtaining a more perfect vacuum in the bulb. Langmuir would not admit this. On the contrary, he was going to fill the electric light bulb with different gases. By studying the bad effects of these known gases, he hoped to learn the causes of the early death of the incandescent lamp. This principle of research he found very useful. "When it is suspected," he declared, "that some useful result is to be obtained by avoiding certain undesired factors, but it is found that these factors are difficult to avoid, then it is a good plan to deliberately increase each of these factors in turn so as to exaggerate their bad effects, and thus become so familiar with them that one can determine whether it is really worth while avoiding them."

First Langmuir got rid of the immense volumes of gases which the tungsten wire had absorbed. Then, instead of working for a more perfect vacuum so that no oxygen would be present in the lamp to attack the wire, he filled the lamp with inactive gases. He chose nitrogen and argon, gases which would not attack the tungsten filament even at the temperature of incandescence. For years he worked persistently with his lamps. He was given the freedom of an Academician, plenty of assistants, and tens of thousands of dollars to continue his work. Whitney was convinced that most of the practical applications of science had sprung from pure scientific curiosity. History had proved this over and over again. Clerk-Maxwell's work on

light, for example, undertaken in the unalloyed spirit of philosophical inquiry, had ushered in modern wireless.

In the meanwhile, the number of research problems had multiplied. Whitney needed more room for his enlarged staff of researchers. The General Electric Company met the situation by erecting a seven-story building into which the little laboratory soon moved. In each of its one hundred and thirty work-rooms every facility of modern scientific research was available—water, illuminating gas, compressed air, vacuum pumps, high pressure hydrogen, oxygen, live steam, distilled water, standard equipment to supply amperage up to twenty thousand and voltage to two hundred thousand, and any temperature between two hundred degrees below zero and three thousand degrees above zero Centigrade. In the building was a library of more than three thousand volumes at the disposal of the staff. This entire plant was maintained by one of the largest annual subsidies devoted to the pursuit of pure and applied knowledge.

Three summers passed without Langmuir finding a single practical application to repay the huge sums of money he was spending. He continued to investigate the problem which had first attracted him, until finally the modern nitrogen and argon-filled tungsten lamps were developed. Langmuir, the theorist, saved America a million dollars a night on its light bill of over a billion dollars a year. But that was not the purpose of his labors at Schenectady. "The invention of the gas-filled lamp," he assured the champions of applied science, "was nearly a direct result of experiments made for the purpose of studying atomic hydrogen (a purely theoretical problem). I had no other object in view when I first heated tungsten filaments in gases at atmospheric pressure."

His study of atomic hydrogen, carried through a period of fifteen years, led, in 1927, to his invention of the atomic hydro-

gen flame for welding metals which melt only at extremely high temperatures. A jet of burning hydrogen molecules, through which an electric current is sent, dissociates into hydrogen atoms which, on recombining, burn with a heat sufficient to melt metals which withstand the high temperature of even the oxy-acetylene flame. These fifteen years of experimentation on purely theoretical problems brought a harvest of important applications in applied science.

When Langmuir first began the study of the tungsten filament heated to incandescence, he dreamed of the disembodied electricity of Thomson. He realized that the scientific progress of the future would be written in terms of electrons. He planned to set the reliable little electron to work. Langmuir was the first electron engineer. His bridges were the molecules, his locomotives were atoms, and his great power machines were the tiny law-abiding electrons rushing through the speedways of copper wires. He saw the heat and light of the electric bulb as the work of electrons passing through the filament.

To help him in his work on the tungsten gas-filled lamp, Langmuir invented the most perfect vacuum pump in existence—the high vacuum mercury pump. This invention was not a chance discovery, but the result of his remarkable powers to see the invisible. From his later researches on vacuum tubes for radio came the plotron and kenotron used in radiotelegraphy; the magnetron, the thyatron, the dynatron, and the pliodynatron, in all of which he set the infinitesimal electron to work. During the war Langmuir also found time to work for the government on submarine detection devices at the Naval Experiment Station at Nahant, Massachusetts.

From the beginning of his studies Langmuir was especially interested in the structure of the atom. Small things had always fascinated him. He followed up every bit of research on this

topic, and added mightily to the store of knowledge. Finally, as the crowning triumph of his career, he postulated a theory of the nature of the atom. Langmuir brought together all the loose threads of physical and chemical research and wove them into a beautiful, harmonious fabric. The clear imagery of this giant of science clarified much that was hazy in our conception of the atom. Out of the mass of theories, experiments and facts concerning the world of the atom, he constructed a beautiful edifice.

The nature of the atom's structure was still very much in doubt. Many had crossed swords with nature to wrest this secret from her. Lord Kelvin had pictured the atom as consisting of mobile electrons embedded in a sphere of positive electrification. J. J. Thomson had developed this same idea but his model, too, had failed because it could not account for many contradictory phenomena. Rutherford's nuclear theory of the atom as a solar system was also objected to as being incomplete. The greatest difficulty to the acceptance of these models was that they all lacked a consistent explanation of the peculiar spectra or bright lines given off by gaseous elements when heated to incandescence.

Even before the discovery of the electron, Hendrik A. Lorentz of Amsterdam had come to the conclusion that these spectral lines were due to the motion of electrified particles revolving around the atoms of matter. He boldly predicted an effect which was later found by his countryman, Pieter Zeeman, in 1896. Zeeman showed that when incandescent gases were placed in powerful magnetic fields their spectral lines were split up. Seventeen years later, a German physicist, Johannes Stark, exhibited a similar undeniable split when the incandescent gases were placed in strong electrical fields. Something electrical in

the atom was the cause of the spectrum of elements—this much was certain.

Back in 1885, Balmer had made another interesting observation. The positions of the lines in the complicated spectrum of hydrogen were not chaotic. They could be represented by a simple mathematical formula. Nature again seemed to proclaim its mathematical proclivity. He noticed that the positions of certain lines of the hydrogen spectrum could be accurately expressed by a number obtained by subtracting two figures. Subsequently other remarkable mathematical relations, like the Rydberg constant, were found.

Still another puzzle which baffled the electronists was this. If electronic motion was the cause of spectral light then Rutherford's atom ought to radiate this light *continuously*. Stationary electrons were inconceivable. Such electrons would be attracted by and fall into the nucleus of the atom unless their stupendous speed around the center of the atom counteracted the powerful pull of the atom's kernel. What the spectroscope had revealed, scientists could not explain by all the known laws of classical electrodynamics. Here was a mighty impasse.

"There are times," said Professor W. F. G. Swann of Yale, "in the growth of human thought when nature, having led man to the hope that he may understand her glories, turns for a time capricious and mockingly challenges his powers to harmonize her mysteries by revealing new treasures." Among those who accepted the challenge was a young Danish scientist, Niels Henrik David Bohr, who was preparing for his Ph. D. degree at the University of Copenhagen. His father was a student of natural sciences and his brother a distinguished mathematician. Niels was to excel them both in the field of science. Eager to learn at first hand the latest developments in the structure of the atom, he went to Cambridge and studied for a time under

J. J. Thomson. Then in the spring of 1912 he went to Manchester to work under Rutherford.

In the summer of the following year Niels Bohr published in the *Philosophical Magazine* an article on the *Constitution of Atoms and Molecules*. For weeks at a time he had lived in Rutherford's laboratory scarcely ever emerging from it. Using Rutherford's conception of the atom as a miniature solar system, he boldly postulated a conception of the dynamic hydrogen atom, the simplest of all atoms, having but a single electron outside its nucleus.

The Dane bravely abandoned his classical mechanics and seized hold of a new key—Planck's conception of quantum of energy. Max Planck had enunciated a revolutionary theory. Energy, he said, is emitted not in a continuous way but only in tiny, finite bundles called quanta. Energy, he insisted, was atomic in structure. Bohr was not afraid to use this unorthodox idea. He pictured the single electron of the hydrogen atom as revolving in an elliptical orbit around the nucleus unless disturbed by some outside force like cathode rays, X-rays or even heat. When thus disturbed, the electron would jump from one orbit to another orbit closer to the nucleus. When electrons leaped in this way light or some other form of radiation was produced. The transfer to each different orbit represented a distinct spectral line. "For each atom," he wrote, "there exist a number of definite states of motion called stationary states, in which the atom can exist without radiating energy. Only when the atom passes from one state to another can it radiate light."

Professor Free has drawn a beautiful analogy to explain Bohr's theory of radiation. He says: "Imagine a series of race tracks one inside the other. Imagine these tracks are separated by high board fences. Put a race horse in the outermost track

and instruct him to run around it until, when he happens to feel like it, he is to jump the inside fence into the next track, run around it for a while, and then jump the next fence, and so on until he reaches the innermost track of all. If, then, you watch this procedure from the field outside the outermost fence, you will not see the horse at all as long as he is running in a single track. The fences hide him. But whenever he jumps from one track into the next, you will see him for an instant as he goes over."

Using this method of attack he cleverly explained Balmer's formula and even deduced this mysterious mathematical relationship by subtracting the calculated energies of electrons before and after jumping. He intimately associated the amount of energy required to move a single electron from one orbit to another with Planck's quantum of energy. He went further and explained that the spectrum of hydrogen was so complex because every sample of hydrogen gas used during any experiment consisted of a large number of atoms in different stages of equilibrium. Sommerfeld verified his conclusions and even succeeded in explaining the "fine" lines of the hydrogen spectrum (two or three lines very close together) by employing Einstein's conception of electrons having varying speeds as well as varying masses.

Niels Bohr provisionally determined the position of the electron of hydrogen, its spectrum and the character of its orbit. The other more complex atoms still defy accurate analysis. He had made use of all the theories and discoveries known to science. By coordinating them he had finally postulated a fairly probable explanation of these phenomena. His thesis brought him undying fame and years later the Nobel Prize. He showed the microcosm of the atom to be a strange world. If we magnify the atom to the size of a football, the nucleus

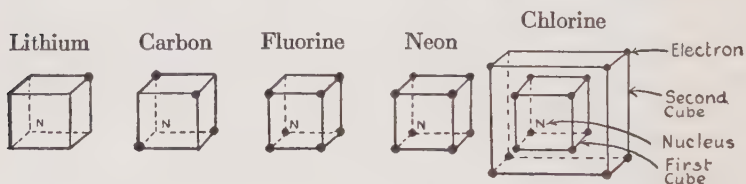
would be but a speck in its center and the electron, still invisible, would be revolving around its surface. Similarly, if we picture the atom as large as the Woolworth Building, the electron, the size of a marble, would be spinning around the building seven million times every millionth of a second. There is relatively more empty space in the atom than between the planets in the solar system. Bertrand Russell, one of England's greatest living mathematicians and philosophers, has expressed this idea rather fancifully. "Science compels us," he writes, "to accept a quite different conception of what we are pleased to call 'solid matter'; it is in fact something much more like the Irishman's net, 'a number of holes tied together with pieces of string.' Only it would be necessary to imagine the strings cut away until only the knots were left." The only thing that gives porous matter the appearance of solidity is the rapid swarming of its electric particles.

Then came Gilbert Newton Lewis of the University of California who worked with mathematical formulas and complicated theories with uncanny precision. He had made outstanding contributions in the field of classical thermodynamics for which he was recently awarded the Davy Medal of the Royal Society of England. He was a lively character. One of his intimate friends has said that "with or without the stimulus of ethyl alcohol, in any company he is the focus of the liveliest discussion, and the center of the merriest group." Born in Weymouth, Massachusetts, ten years before Niels Bohr, he had studied at the Universities of Nebraska, Harvard, Leipzig, and Göttingen, where, like Langmuir, he received his doctor's degree. While lecturing at Harvard he was known to "pace back and forth across the platform covering miles at breakneck speed." His was a versatile personality.

Lewis, one of the first Americans to discover Einstein, was

a theorist of the highest order. As early as 1902 he was pondering over the structure of matter and had already conceived the *cubical* atom. This was two years before J. J. Thomson had proposed an atomic model in which electrons were distributed in a system of concentric rings lying in one plane. Lewis loved to speculate and play with fanciful theories and intricate formulas. Just before he left for France in 1916 as head of the Defense Division of the Chemical Warfare Service, he published a paper which laid the basis of the modern theory of the static atom, as developed a few years later by Langmuir. In every atom, said the California professor, is an essential nucleus which remains unaltered. Around this nucleus are cubical shells containing varying numbers of electrons which occupy fixed positions. Every atom tends to get one electron on each of the eight corners of its cube. Lewis based this *octet* theory upon the vast store of chemical and crystallographic properties of substances which had accumulated, and not, as Bohr had done, on the scanty physical data then at his disposal.

According to Lewis the following represented the atoms of



This was the state of our knowledge of the structure of the atom when Langmuir, the modern scientific conquistador, attempted to invade the tiny world of the atom. There was an unmistakable conflict between Bohr's theory of the hydrogen atom and the conception of Lewis. Chemists could see but little use in the Bohr atom. They wanted an atom which would explain chemical reactions. The World War over, Langmuir



IRVING LANGMUIR

undertook to reconcile the two theories by publishing his *concentric shell* theory of atomic structure.

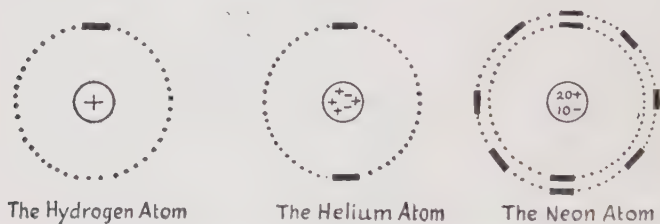
One hundred and fifty years ago Lavoisier tried to find the cause of the different behaviors of the elements. Why, for instance, was chlorine so violently active, while nitrogen and gold were almost completely inactive? Like thousands of other scientists, Lavoisier failed to explain this strange phenomenon. "The rigorous law from which I have never deviated," he wrote, "has prevented me from comprehending the branch of chemistry which treats of affinities or chemical unions. Many have collected a great number of particular facts upon this subject. But the principal data are still missing."

The great Berzelius half a century later was still puzzling over this question. "We ought," he wrote, "to endeavor to find the cause of the affinities of the atoms," and he suggested a possible method of attack. "Chemical affinity," he believed, "is due to the electrical polarity of the atoms." With the tremendous strides made in theoretical and applied chemistry, the solution of this important question still remained undiscovered.

Irving Langmuir, dreamer and practical engineer, saw in his conception of the tiny cosmos of the atom a probable explanation. Moseley's table of atomic numbers was his starting point. The inert gases of the atmosphere which had led him a merry chase in his researches on the gas-filled tungsten lamp were to furnish the clew to the cause of chemical activity.

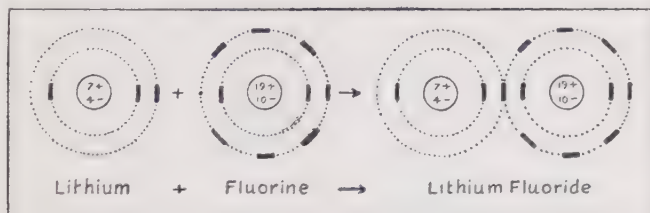
The elements helium (atomic number 2) and neon (atomic number 10) were two stable elements. In these atoms the electrons outside their nuclei must therefore represent stable groups which rendered their atoms incapable of chemical activity. Langmuir pictured helium as containing a nucleus of fixed protons and cementing electrons, and two additional electrons revolving in a shell outside the central core. The distances

between the shells were made to agree with the various orbits of the Bohr atom. These two electrons around the nucleus constituted a stable configuration. All atoms, said Langmuir, have a great tendency to complete the outermost shell. This tendency to form stable groups explains the chemical activity of the atom. Hydrogen is very active because its shell, containing but one electron, is incomplete and needs another electron to form a stable group of two electrons, as in helium.



Neon, with ten electrons outside its nucleus, represents another stable configuration having two electrons in its first shell and eight more in a second larger shell concentric with the first. (Kossel, three years before in Germany, in attempting to construct a ring system which would correlate electronic shells with chemical valencies had also assumed a configuration of eight electrons as stable.) All the elements with atomic numbers between 2 and 10 are, therefore, active to an extent depending upon the completeness of their second shells. For example, lithium, atomic number 3, possesses only one single electron in its second shell, and hence in its eagerness to have its outside shell complete will readily give away this third electron to another element, and thus have left but two electrons in the first shell—a stable group. This tendency to lose electrons from the outermost incomplete shell makes lithium an extremely active substance. Fluorine, atomic number 9, shows two electrons in its first complete shell, and seven additional electrons

in its second shell. It needs but a single electron to complete its second shell of eight electrons. Hence it, too, shows a violent tendency to capture an electron, thus manifesting extreme chemical activity.



Atoms, said Langmuir, differ from each other in chemical activity only because of their tendency to complete their outside shells and thus render the atom stable. Argon, the third inert gas in Moseley's Table of the Elements, has an atomic number of 18. Its first shell is complete with two electrons, its second shell is also complete with eight additional electrons, while its third shell likewise contains eight electrons, showing once more a stable configuration. Hence argon is inert. Chemical affinity is thus a condition dependent upon the nature of the outermost shell electrons. When the outside shell of an atom contains very few electrons, its tendency is to lose them. Such an atom is a metal. If, on the other hand, the outermost shell of an atom contains an almost complete ring, it will strive to borrow some electrons from other atoms which are anxious to lose them. Such an atom is a non-metal. Metals are lenders of electrons and non-metals are borrowers. Hence metals and non-metals will combine energetically with each other and both, by an exchange of electrons, assume the stable condition. Chemical affinity or union, therefore, depends upon this transfer of electrons. In a polar union a positive atom loses its valence electrons to a negative atom and the two atoms are held by

electrostatic attraction. In a non-polar union electrons are not actually transferred—the two atoms approach each other so that one or more valence electrons of one atom occupy the vacant positions in the valence shell of the second atom. Octets are thus formed by a process of sharing electrons.

The concentric shell theory of Langmuir solved other riddles. It explained valency—the tendency of elements to combine with one or more atoms of hydrogen. Valency had baffled chemists ever since Frankland, an English chemist, had introduced the idea about seventy-five years ago. Valency, according to Langmuir, is the number of electrons which the atom borrows or lends in its effort to complete its outside shell. Thus chlorine, which borrows but one electron, has a valency of one, which means that it combines with but one atom of hydrogen.

Langmuir's conception of the structure of the atom also threw a flood of light upon the meaning of isotopes—atoms of the same chemical and physical properties but differing in mass. Since chemical affinity depends upon the electrons in the outermost shell, Langmuir believed isotopes to have the same number of electrons outside the nucleus. Since, however, they differ in weight, Langmuir postulated quite rationally that the nuclei of isotopes differ by having different numbers of protons in their central cores. Thus the two isotopes of chlorine may be represented as:



Each has seventeen free exterior electrons of which seven are in the outermost shell. Their nuclei, however, are different, the

second isotope having two protons and two electrons more in its nucleus than the first. *Isobares*, different elements with *identical* atomic weights, were also explained. The last three isotopes of selenium have the same atomic weights (78, 80, 82) as the first three isotopes of krypton, yet the physical and chemical properties of these isobares are totally different from each other. The number of electrons in their outermost shells are different.

What a simple, beautiful conception of the atom Langmuir gave us. Chemical science now began to approach prophecy, for, knowing the atomic number of an element, we can, with certainty, arrive at its properties without even seeing the element. In 1919, Langmuir received the Nichols Medal award for this arrangement of electrons in atoms.¹⁸

The Jesuit, Athanasius Kircher, centuries before, made the statement that "alchemy is a science not yet known but which may become known." Langmuir has brought us a little nearer to this possibility. His conception of the structure of the atom makes it possible for the present-day scientist to explain the riddle of transmutation. Modern alchemy is a very different art from man's greedy striving to change lead into gold and grow gold in dunghills. To-day, armed with centuries of research which culminated in Langmuir's picture of the atomic world, chemists may hope to change the base metals into precious minerals not by the blind necromancy of zealous alchemistical adepts, but by clear, honest, explicable methods of controlled experimentation.

All the ninety-two atoms of the material universe differ only in the number of positive protons in their nuclei and the number of electrons outside their kernels. Hence we can, by changing this number of electrons and protons, transmute the elements one into another. Nature performs this transmutation with radium, uranium and other radioactive metals. (Uranium,

atomic number 92, passes finally into lead, atomic number 82.) Rutherford changed nitrogen into helium—an unquestionable transmutation of one elementary gas into another. The only obstacle in the way of a commercialized transmutation of lead into gold to-day lies in the difficulty of obtaining forces powerful enough to tear away or add electrons to the atoms at will, and at a cost which could compete with the price of gold. Perhaps its solution lies in the discovery and utilization of some catalytic agent whose presence in minute amounts would continue the transmutation which was once started.

Says Professor Arthur Stanley Eddington, the eminent mathematician and astronomer of Cambridge: "We started to explore the inside of a star and soon found ourselves exploring the inside of an atom. In the star, dishevelled atoms tear along at a hundred miles a second, their array of electrons being torn from them in the scrimmage. The lost electrons are speeding a hundred times faster to find resting places." In the great milky way, that starry swarm in the heavens, temperatures and pressures that stagger the imagination by their intensity are ripping electrons from atoms and breaking heavier elements into lighter ones. The same process is undoubtedly going on in the sun whose interior temperature has been estimated to be almost fifty million degrees—a temperature, says Jeans, which, if maintained by a pea, would shrivel up a man a thousand miles away in the flick of an eye-lash. On the sun's surface the spectroscope has revealed such products of atomic disintegration as free electrons, helium and X-rays.

Can man imitate the forces of nature's celestial furnaces? He has tried to make and throw lightning bolts. At the opening of the High Voltage Laboratory of Stanford University a few years ago, Dr. Harris J. Ryan condensed more than a million volts of electricity into an artificial lightning bolt ten feet long.

More powerful currents have been obtained in the High Voltage Laboratory of the General Electric Company at Pittsfield, Mass., where F. W. Peek made twenty-foot lightning flashes by means of five million volts of electricity.

Over in Europe men have attempted to harness nature's flaming thunderbolts of one hundred million volts in an endeavor to disrupt the atom. On Mt. Generoso, six thousand feet high, in the Swiss Alps, three German scientists of the University of Berlin, are watching through their specially constructed lightning-proof cabin nature's titanic display of lightning on a twenty-five hundred foot aerial, which they stretched between two crags. These fifteen-foot flashes of lightning, coming in rapid succession and representing a thousand billion horsepower of energy, are being harnessed in the attempt to transmute the elements.

Other efforts have been made to disrupt the nucleus and tear away a single electron from the mercury atom which has eighty electrons outside its nucleus, and thus obtain gold, containing seventy-nine outer electrons. In 1924 came reports from Germany that Drs. Miethe and Stammreich had sent high voltage currents through quartz mercury-vapor lamps for weeks at a time. By this process they hoped to steal electrons from atoms of mercury and thus transmute them into the more valuable gold. They found extremely minute quantities of gold in the black deposits which formed on the glass walls of the lamp. The following year news came from Japan that Nagaoka¹⁹ and his co-workers had obtained traces of gold by passing electricity across terminals of mercury and tungsten. They had also tried spark discharges on the surface of mercury emulsified with oil, and their spectroscopic examinations seemed to indicate the presence of traces of the yellow metal.

Immediately, in many of the world's scientific laboratories,

similar experiments were tried out to verify such startling transmutations. The evidence, however, proved negative. In all cases the minute traces of gold were found to be due to impurities either in the mercury used or, in one case, to the gold eyeglasses which one of the experimenters aiding Miethe had worn and handled during these delicate investigations. Perhaps minute specks of gold have actually been made from pure mercury. Theoretically, it is altogether possible. But the commercial synthesis of gold is still a problem for the future. The forces that hold the atom's electrons in their tiny orbits are colossal. It has been calculated that it would take a million and a half barrels of powder to give a rifle bullet the speed of the electron. To disrupt even a mote travelling at this dizzy speed would require stupendous forces which man has not yet learned to control.

Mankind is no longer profoundly interested in alchemy. Were commercial transmutation made possible to-morrow, it would not revolutionize the existing order of things. But there is another problem in which science is decidedly interested, for it may mean the renascence of the whole world. Man's supply of energy is of far greater importance than the industrial synthesis of gold from lead or iron. The study of the atom may unlock a new source of energy which would dwarf the immense stores of power obtainable from coal and petroleum.

If we could but harness the energy of the tiny electron spinning around its own tremendous sun at staggering speeds, we would be in possession of forces inconceivably great. We could stoke our furnaces forever. J. J. Thomson has estimated that the energy from the whirling electron in a single gram of hydrogen atoms would be sufficient to lift a million tons three hundred feet. One ounce of helium, while being built up from hydrogen, would yield a million horse-power for seven hours.

Atom building and atomic decay may be the sources of the world's future supply of energy.

Professor Fritz Paneth of the University of Berlin worked for three years trying to condense helium from hydrogen by means of the metal palladium. In 1926, his spectroscopic examinations seemed to indicate minute traces of helium. Other scientists tried to duplicate these experiments in the hope of verifying the results. Dr. G. B. Kistiakowsky, research fellow at Princeton University, repeated the experiments of the German researcher, but reported negative results. Paneth withdrew his claims, having subsequently found that a leak in his apparatus was responsible for the presence of helium.

Yet interatomic energy is no idle dream. Every Nobel Prize winner in the physical sciences believes it possible of attainment. Sir William Bragg, of crystal fame, has stated his beliefs: "I am of the opinion that atomic energy will supply our future need. A thousand years may pass before we can harness the atom, or to-morrow might see us with the reins in our hand." At the present time we cannot pick the lock that holds this enormous reservoir of energy.

Sir James Hopwood Jeans, British mathematician and astronomer of the Royal Society, maintains that the sun is wasting away, its tremendously great supply of heat energy being maintained by the disintegration and explosion of atoms in the sun. As the elements disintegrate, immense masses of electrons are shot out and become converted into radiant energy. He pictures a gradually disappearing world. "The fabric of the universe," he says, "withers, crumbles and dissolves with age, and no restoration or reconstruction is possible. Our position is that of polar bears on an iceberg that was broken loose from its ice-pack surrounding the pole and is inexorably melting

away as the iceberg drifts to warmer latitudes and ultimate extinction."

These are gloomy forebodings, but mankind may take heart, for a counter building-up process in the universe has recently been discovered. Robert A. Millikan and G. Harvey Cameron of the California Institute of Technology announced on April 23, 1928, some startling experiments. They went to the summits of high mountains, sent captive balloons far up in the heavens, explored the depth of snow-fed mountain lakes where the bombardment of stellar light could be measured, and turned their delicate spectrosopes to the stars. Not in the stars, as was supposed, but in the interstellar space where the temperatures are closer to absolute zero, they found evidence of a reconstruction process among the atoms. In this frigid region, billions of miles away, radiant energy was changing by condensation into new atoms. When the atoms merged to form new elements, rays were produced. These new powerful rays which pass through two hundred feet of water or eighteen feet of solid lead (the strongest X-rays are absorbed by three inches of lead) were detected by an instrument similar to that which the Curies used to find radium. The secret of creation was revealed to them by these super X-rays. The American scientists estimated that some of these rays had frequencies corresponding to the energy that would be set free in the synthesis of helium from hydrogen. These *cosmic rays*, as Millikan named them, "are in fact the birth cries of the infant atoms of helium, oxygen and silicon. We have some little indications that we can also hear the shriller birth squeaks of infant iron." As the more stable and abundant elements like helium and oxygen are created from the primordial positive and negative electrons of hydrogen, the news is broadcast in the form of their appropriate cosmic rays. They have found an evolution among the elements of the inor-

ganic world just as, three generations back, Darwin announced organic evolution.

Another perhaps more immediate thought presents itself to the scientific dreamer. As man pries off the covers that hide the secrets of the atom, he may unearth wonders which may bring the millennium when men will guide the tiny atom in doing the world's work, while he has the leisure to do still greater things. Man may then find a theory of nature which will make him either robot or demigod. But in this mastery lurks also the danger of cosmic disaster. Some super-scientist groping and tinkering with this mighty force may unknowingly set off the most tremendous bomb which could destroy mankind and the planet on which it has its being. Practical scientists have asked the question: "Could not some sudden shock let loose this terrific energy, much as a detonator explodes dynamite, and so cause the whole world to disappear in one enormous flash of light? The glare of this catastrophe would be heralded to the distant worlds of space but by a new star shining brightly in the skies."

As men advanced from ancient abstract philosophy to modern scientific experimentation, problems of greater and more vital importance appeared. As each problem rose, men were born to wrestle with the new mysteries. Guided by a divine inspiration or some mystic impulse, these men have brought us nearer to the riddle of the universe.

Irving Langmuir, to-day, is Assistant Director of the Research Laboratory of the General Electric Company. This eminent chemist and physicist is interested in research and young men. Even as Whitney twenty years back saw a great promise in him, Langmuir has great faith in the young research worker in science. He believes with that great protagonist of evolution, Thomas Huxley, who half a century ago exclaimed: "I would

make accessible (to the scientist) the highest and most complete training the country could afford. I weigh my words when I say that if the nation could purchase a potential Watt, a Davy, or a Faraday, at the cost of a hundred thousand pounds down, he would be dirt cheap at the money."

President Hoover has recently expressed the same conviction. "Our scientists," he said, "are amongst our most priceless national possessions. There is no sum that the world could not afford to pay these men. Not by all the profits of all the banks in the world can we measure the contribution which these men make to our progress. The nation needs to-day more support to research. It needs still more laboratories." Of the two hundred million dollars which is spent for scientific research in the United States each year, the Government alone spends one-third this amount. But this is only a beginning.

Langmuir and others like him in the host of university and industrial research laboratories of the world are training a new band of scientists who, equipped with more powerful tools, broader vision and scientific idealism will push on towards science's unbounded horizon. There will always be such men. The vast procession of the saints of science will continue to pass on in majestic array. Perhaps still greater minds will yet see the light of day. To the dominion of science there is no end.

EPILOGUE

THE STUFF OF MATTER IS BUT A WAVE

AT THE Minneapolis Meeting of the American Chemical Society in 1929, Professor K. F. Bonhoeffer skillfully demonstrated something new in chemistry. This German, still in his twenties, had come a long way from the Kaiser Wilhelm Institute of Berlin to perform a novel experiment. He passed ordinary hydrogen gas through porous charcoal cooled to four hundred and fifty degrees below the freezing point of water. At this frigid temperature the charcoal, acting as a catalyst, absorbed large quantities of an almost pure form of hydrogen called *para-hydrogen* which he kept stable for several days under normal conditions of temperature and pressure.

To prove that *para-hydrogen* differed from ordinary hydrogen he pumped the former over a hot wire where it interfered with a flow of heat, the interference being made visibly evident by a spot of light thrown on the wall of the lecture-room. Then, by means of platinized asbestos, he easily converted *para-hydrogen* into a second variety of gas, *ortho-hydrogen*, which was likewise passed over the hot wire. The spot of light on the wall changed.

Chemists and physicists inured to startling experiments were stunned. Karl Bonhoeffer had actually separated pure hydrogen gas into two varieties of the same element—a feat which hitherto had been considered impossible since its molecule, made up of two atoms of hydrogen and containing but two protons and two electrons, was the simplest one known. The two brands of hydrogen differed not only in their heat conductivities but more particularly in their specific heats, that is, the quantities of heat

necessary to raise a gram of each substance one degree Centigrade.

The spot of light which Bonhoeffer threw on the screen was like the handwriting on the wall. Dr. Irving Langmuir was there as President of the American Chemical Society. He saw in this ingenious demonstration something actually revolutionary in chemistry. This achievement was remarkable not so much because hydrogen was shown to be a mixture of two forms of the same element, but chiefly because here was a concrete example of a major contribution to chemistry from a new field of atomic research, developed wholly by the physicist and the mathematician.

For a little more than ten years Planck's quantum principle as applied to the structure of the atom had rendered noteworthy service. But both the brilliant formulations of the Copenhagen School led by Niels Bohr, and the Lewis-Langmuir theory of the atom as developed in America contained dark spots which no amount of experimentation could illuminate. The isolation and measuring of the electron and proton, conclusive as were these achievements, did not satisfy all scientists. There were certain undeniable and flagrant inconsistencies which neither a material nor an electrical particle could explain away. The experimental facts connected with the intensities of the spectral lines of the elements, for example, proved an immovable objection to the acceptance of these theories.

Already from the field of light had come rumblings of a violent upheaval in the definitions of science. Newton and his predecessors had believed rays of light to consist of discrete particles or corpuscles too small and buoyant to be measured. This corpuscular theory of light had been generally accepted until the opening of the nineteenth century when Thomas Young and later Auguste Fresnel, independently of each other, showed that,

under certain conditions, rays of light could be made to interfere with each other to produce darkness. This phenomenon of *interference* could not be explained by any corpuscular theory. Interference, however, could be easily understood if light were considered as being of the nature of waves in a hypothetical medium, the ether, invented to transmit the light waves. Just as the crest of one water-wave falling in the trough of a second water-wave fills it, and makes the surface of the water level at that point, so, maintained Young, light waves may meet and interfere with each other to produce darkness.

This undulatory theory of light, intrenched for a full century, in turn received a rude jolt. Hallwachs, in 1888, found that a beam of light falling on a negatively charged body produced a rapid loss of the charge, while a non-electrified body gradually became positively charged in the presence of light. No explanation could be offered for this strange behavior until two years after the discovery of the electron. Both J. J. Thomson and P. Lenard showed that the emission of negatively charged particles or electrons from the surface of the metal was the cause of the phenomenon which Hallwachs was the first to observe. Three years later, Lenard proved that the speed of the emitted electrons depended only upon the color or wave-length of the light no matter how feeble. Further experimentation demonstrated that the *number* of electrons thrown out from the metal depended upon the *intensity* of the light. Here was another enigma for science to unravel. How could light, made up of waves in the ether, release electrons from the atoms of metals? The established concept of light was powerless to answer this baffling question.

In 1905, Albert Einstein, employed as examiner of patents in the patent-office of Berne, made a bold attack upon this problem. In his now-famous paper, this German-Swiss scientist of twenty-

five theorized that the emission of electrons from metals by light could be explained by assuming that light consisted not of waves but of *photons* or concentrated bundles of energy travelling with the speed of light. Each photon or particle of radiation as it struck the metal surface gave up its energy to an electron and dislodged it from its atom.

In attempting to confirm Einstein's picture of this queer photoelectric effect (the basis of television), scientists delved once more into the possible structure of the atom and the nature of its electrons. If light is of a dual nature, exhibiting at one time the properties of a wave and at another the characteristics of a particle, then, perhaps, all the stuff of the chemist might show this same duality. Perhaps matter itself was of a wave nature, and the paradox of light would find its consort in the paradox of matter.

In a private laboratory in Paris worked Prince de Broglie, scion of a family of French noblemen whose history dates back to the seventeenth century. One of his direct ancestors was Marshal of France under King Louis XV, while his great-grandfather, Victor-Claude, Prince de Broglie was a member of the Constituent Assembly and served as Lafayette's chief Lieutenant during the American Revolution. This Jacobin, who admonished his young son to be faithful to the principles of the Revolution, however unjust it might be to him, was guillotined a month after the execution of Lavoisier.

Louis-Victor, Prince de Broglie at thirty-two had been admitted to the French Academy of Sciences. He had been trained under the excellent guidance of his older brother, Maurice, Duc de Broglie, who for more than two decades had made notable contributions in the fields of X-rays, electrons and electricity. Louis de Broglie, in his study of black radiation and light quanta, was gradually led to what seemed to him an inevitable



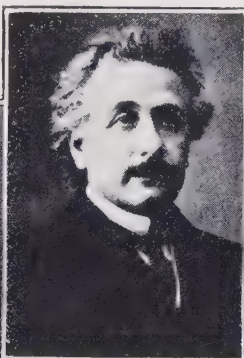
PRINCE LOUIS DE BROGLIE



C. J. DAVISSON AND L. H. GERMER
(Courtesy Bell Telephone Lab.)



G. P. THOMSON



ALBERT
EINSTEIN



MAX PLANCK

LEADERS IN THE FIELD OF WAVE MECHANICS

conclusion that light and electrons were similar. Seeing an imperative need for a new conception of matter which would be applicable to the structure of the atom as conceived by both chemists and physicists, and at the same time permit of an explanation of the paradox of light, he brilliantly enunciated a theory of the electron as revolutionary as the most sweeping hypothesis of the century. In a paper published in 1924 he suggested that the electron was not altogether a particle of electricity. The electron, he thought, was composed of, possessed, or perhaps was attended by a group of waves which guided its path. He associated the motion of a particle with the propagation of a wave and related the energy and momentum of a particle with the frequency and velocity of the wave. By using the terminology of radiation for an atom of electricity and considering the electron as the wave itself, he calculated a definite wave-length for his electron.

If de Broglie's electron was of the nature of Young's rays of light then the electron ought to exhibit the peculiar characteristics of ether waves, namely interference and diffraction. For two years after de Broglie's hypothesis had been advanced no direct proof of its validity could be mustered. But in 1927 the experiment which men of science either scouted or awaited with bated breath came from America.

This most important discovery of the year was made in the research laboratories of a private industrial corporation, the Bell Telephone Company of New York. This was the probing ground of two men—Dr. Clinton J. Davisson and Lester H. Germer, a graduate student of Columbia University. Davisson had been graduated from the University of Chicago in 1908, and later, at Princeton University, under the direction of Professor Owen W. Richardson, had been drawn to thermionics. This new branch of science which deals with the emission of ions and

electrons from heated bodies was Richardson's own particular field, the laws of which he had discovered. Langmuir, too, had been attracted to this promising sphere of research and had made notable contributions to it.

Davisson had acquired a remarkable technique in his study of ions and electrons, and after de Broglie had astonished the world with his concept of electron waves he set to work to investigate it. For three years, with the aid of young Germer, Davisson experimented on the scattering of electrons from metal surfaces when bombarded both with ionized gas molecules and streams of electrons. Finally one day, from their graphs and figures, they discovered that a sharply defined stream of electrons after striking a small plate cut from a single crystal of nickel, left the crystal in the direction of regular reflection. The angle of incidence of the stream of electrons was equal to its angle of reflection.

How could this action be accounted for? The surface of a crystal was made up of atoms very much larger than the tiny material electrons which struck the surface of the metal. How could these electrons rebound from such a surface with such regularity? "It is," said Germer, "like imagining a handful of birdshot being regularly reflected by a pile of large cannon balls. A surface made up of cannon balls is much too coarse to serve as a regular reflector of particles as small as birdshot." The reflection of the narrow beam of electrons from the nickel crystal indicated that the electrons were striking the crystal and were being reflected from the crystal in the same way as rays of light behave. Davisson and Germer drew their conclusion: "Our experiments establish the wave nature of moving electrons with the same certainty as the wave nature of X-rays has been established."

Here was the first fruit of de Broglie's daring assumption

which had served as the guiding principle in this historic experiment. The scientific world carefully weighed the results of the Davisson-Germer discovery. Albert Einstein, the most profound scientific thinker since Newton, could not refrain from exclaiming: "We stand here before a new property of matter for which the strictly causal theories hitherto in vogue are unable to account." Physics and chemistry, turning an unexpected corner, had met and found themselves in need of new moorings.

Sir Joseph John Thomson had given the electron to the world and had spent a life of research in its clarification. Then came his son, George Paget Thomson, trained by his father at Trinity College in the complicated field of electron mechanics. This younger Thomson, who was born in the same year as Louis de Broglie, had shown, even as a student, unmistakable promise in the field of science. He had won First Class honors in the Mathematical Tripos and shared honors in the Natural Science Tripos. Turning from aerodynamics into which he had been led as an officer in the British Army during the World War, he tackled the problem with which de Broglie had wrestled. Perhaps, after all, his father's electron was not altogether what the world believed it to be.

While Professor of Natural Philosophy at the University of Aberdeen, he started to investigate the nature of the electron to strengthen the old concept or demolish it. If the electron consisted of waves it ought to exhibit the optical phenomenon of diffraction, that is, a change of direction as it passed from one medium like a solid metal to another like a vacuum or air. In the summer of 1927, G. P. Thomson sent rapidly moving electrons, the kind that Davisson was using, against extremely thin sheets of gold and other metals. He took hundreds of photographs of the area behind the metallic films and found unmistakable evidence of the diffraction phenomenon of waves.

A few months later the son of the master of the electron told the Royal Society of England something more startling perhaps than his father had told it thirty years back. The old picturesque conception of the electron as an atom of negative electricity was an outgrown image. There was no such thing as a material electron such as his father had described. "One may picture the free electron," declared the younger Thomson, "as something like a gossamer spider floating through the air at the center of a number of radiating filaments which control its flight as the air wafts them about, or as they are caught by solid objects." To-day, as visiting lecturer at Cornell University, he claims for this new conception of the electron as a wave motion "more prospect of accounting for the facts of chemistry than have the orbits" of Bohr and his school.

Recognizing the dual nature of light, X-rays²⁰ and the electron, G. P. Thomson predicted that the proton also would eventually show this duality of wave and particle. Before long, many left less urgent researches to join in this gripping adventure. Among them was Arthur J. Dempster who had first shown positive proof of the existence of isotopes of magnesium. In the Ryerson Physical Laboratory of the University of Chicago, he plunged into the problem of discovering the nature of the proton. Hydrogen atoms were stripped of their electrons in a vacuum tube and then directed against a small calcite crystal. By their rebound he was convinced that the positively charged hydrogen atoms or protons were striking the crystal as waves rather than as tiny balls. This fulfillment of Thomson's prophecy made such a strong impression that Dempster was immediately awarded the annual thousand dollar prize of the American Association for the Advancement of Science at its 1930 meeting held in Des Moines, Iowa.

Both the Davisson-Germer experiment and its counterpart

as performed by Dempster were accepted as verifying the theory of de Broglie which coordinates waves of ether with flying particles. In 1929 Prince Louis de Broglie was honored with the Nobel Prize for his work which culminated in the theory that the stuff of all matter is but a wave.

In the meantime there began an orgy of speculation in the field of the physical sciences. Physical and mathematical theories of the structure of the atom came "crowding on each other's heels with an increasing unmannerliness." In the forefront of these hypotheses stood that of Erwin Schroedinger, Professor of Theoretical Physics at the University of Zürich. This Austrian scientist, son of the botanist Rudolf Schroedinger, had been born in 1887 and had been graduated a Doctor of Philosophy in Science from the University of Vienna. Schroedinger had been attracted to the work of de Broglie and had discussed it with Einstein who saw a great promise in it. By a remarkable interpretation of the work of the Frenchman, Schroedinger finally developed an entirely new system of wave mechanics in which he attempted to depict and explain all atomic and electronic phenomena.

Advancing along the lines of de Broglie's concept of a material electron associated with trains of waves, Schroedinger abandoned the material electron altogether and assumed the electron to be nothing else than a train or series of waves. "If the waves work so well why a material electron at all?" he asked. "Material points," he insisted, "consist of or are nothing but wave-systems." Developing this idea further he arrived at the conclusion, from intrinsically mathematical and somewhat metaphysical reasonings, that an atom of hydrogen was but a region permeated by waves. "A single atom," he declared, "extends out into infinite space. The nucleus degenerates into an electrical hole in the center of the aura." His system postulated

a sub-ether whose surface is covered with ripples or wavelets which are beyond our ken but whose disturbed area of ripples was the old electron or particle. The mathematical equations of his theory predicted the periods, intervals and intensities of many spectral lines which accurately confirmed the work of de Broglie. His wave mechanics seemed to agree with the facts of spectroscopy much better than the treatment of Niels Bohr.

At the same time, an equally profound and suggestive idea was being evolved by a student of theoretical physics of the University of Göttingen. Werner Heisenberg, son of a professor of philology of the University of Munich, was convinced that some principle could be found which could fully explain the peculiarities of the spectra of the elements without introducing into atomic structure those factors which are not directly open to observation. He considered as unscientific not only the established conception of velocity of electrons within the atom but even the definite positions of these electrons. With one defiant stroke, this boy of twenty-three discarded all of Bohr's pictures of electronic orbits which had never been observed.

Heisenberg expressed the structure and composition of the atom as well as other concepts of physical philosophy by mathematical formulas which he directly connected with the frequencies and intensities of the spectral lines of the elements—phenomena which could be observed and accurately measured. This departure was, of course, laudable, but his efforts to include into his scheme of the atomic world all the known facts of physics and chemistry resulted in the formulation of a system, the New Quantum or Matrix Mechanics, which bothered even men accustomed to the twists and spirals of serpentine theoretical physics. Schroedinger, himself, whose own theories resembled those of Heisenberg, told his friends he had been

“discouraged if not repelled by its difficult methods of transcendental algebra.”

In the summer of 1927, Heisenberg published in the *Zeitschrift für Physik* another paper in which he enunciated what is known as the Principle of Indeterminacy. He postulated that “a particle may have position or it may have velocity but it cannot in any sense have both.” The clearly defined electron which Millikan, its measurer, had called in 1923 “neither an uncertainty nor an hypothesis but a new experimental fact which any one who wills may henceforth see” was now nothing but a ghost completely swamped under the waves of the newer cult of young theorists. Nothing was left of J. J. Thomson’s electron but its mirage in the form of waves in the ether—some mysterious something as vaporous as phlogiston and caloric. Men like Born, Jordan, Pauli and Brillouin, playing with the mathematical formulas of Schroedinger and Heisenberg, constructed a highly complex system which, without the electron, seemed to account for the spectral lines which had baffled both the physicist and the chemist for decades.

It is remarkable that the wild speculations of the last five years which changed the electron into a “dummy electron” have actually produced some astonishing results. Heisenberg, through abstruse calculations, succeeded in explaining the complex spectrum of helium. Then Hund, from analogy of the behavior of the helium atom, predicted, after studying the band spectrum of the hydrogen molecule, that hydrogen gas under normal conditions ought to consist of two forms of hydrogen. These two forms were present in ordinary hydrogen gas in the ratio of three to one.

This was a clew to the peculiar variations of the specific heat of hydrogen gas at different temperatures, for which existing theories were at a loss to account. Hund theorized that the

nuclei of the two atoms of the hydrogen molecule were spinning in opposite directions while in the molecule of a second variety of hydrogen the nuclei were spinning in the same direction, conditions which would account for two varieties of hydrogen gas having different specific heats.

Karl Bonhoeffer and P. Harteck, picking up the trail at this point, began experiments in Berlin on the heat conductivity of ordinary hydrogen gas and finally succeeded in making a simple experimental verification of Hund's prophecy by transforming one form (ortho) into another pure form (para) with the aid of frigid charcoal. This contribution to chemistry from the field of wave mechanics is epochal. Langmuir has expressed the opinion that it would have been fifty years before para-hydrogen would have been discovered by the use of ordinary methods even though no new knowledge or technique is involved in its isolation. He believes that the whole future of theoretical chemistry depends on the application of physics and the quantitative theory of mathematics more so than any man has ever yet dreamed. Chemistry may expect more contributions from the mental jugglery of mathematicians and physicists struggling to understand the nature of the universe.

The field of the sub-atomic world beyond the electron is becoming more embarrassing than ever. Serious-minded men are wondering once more whether nature is really consistent and orderly. Scientists are beginning to doubt whether the reality of nature and the laws of nature which they seek have any real meaning. Eddington is sceptical about finding a complete view of nature in science. Bertrand Russell would give up the eternal struggle for "final truths belong to heaven, not to this world." Some natural philosophers, helplessly befuddled by the cataclysmal disclosures of the last three decades, are actually in

retreat. The whole established edifice of science seems to be in need of overhauling if nature is to be made to appear orderly.

Yet science is not doomed. In the great upheaval of existing beliefs and in the débâcle which is destroying many of our old conceptions "some fact of which we are entirely ignorant and whose discovery will revolutionize our views of the relation between waves and matter" will be upturned or stumbled upon by some young demi-urge aching to rebuild a shattered world.

Perhaps, after all, in this phantasmagoria which has emerged we are on the threshold of a tremendous revolution in our conception of the universe we live in. "Mankind is at the very beginning of its existence," says Sir James Jeans, "and has only just begun to notice the cosmos. It is hardly likely to interpret it right in the first few moments its eyes are open."

AS WE CONQUER PEAK AFTER PEAK WE SEE IN FRONT OF US REGIONS FULL OF INTEREST AND BEAUTY, BUT WE DO NOT SEE OUR GOAL, WE DO NOT SEE THE HORIZON: IN THE DISTANCE TOWER STILL HIGHER PEAKS, WHICH WILL YIELD TO THOSE WHO ASCEND THEM STILL WIDER PROSPECTS.—*Sir Joseph John Thomson.*

THE END

NOTES

¹ From Ben Jonson's *The Alchemist*.

² Quotation from *The Dying Alchemist* by N. P. Willis.

³ From Browning's *Paracelsus*.

⁴ From George Eliot's *Middlemarch*.

⁵ From J. P. Cooke's *The New Chemistry*.

⁶ Priestley, called the Father of Pneumatic Chemistry, also prepared and collected sulphur dioxide gas.

⁷ Cavendish anticipated Coulomb in the discovery of the inverse square law of electrical attraction, but his work remained unpublished until long after his death.

⁸ Quotation from Youmans' *New Chemistry*.

⁹ Among his pupils was James Prescott Joule who, at ten, was sent by his father to study mathematics under Dalton. It was this boy who, twenty-five years later, gave the world its first complete explanation of the Law of the Conservation of Energy.

¹⁰ Between 1821 and 1848, the year of his death, Berzelius published his famous *Jahresberichte*, twenty-seven volumes of complete yearly reports on the progress of chemistry and physics.

¹¹ Hans Oersted, a Danish scientist, probably made aluminum in 1825 by extracting it from aluminum chloride by means of potassium amalgam. Woehler repeated this experiment and obtained pure aluminum two years later.

¹² The basic principles of Arrhenius' theory are as firm as ever. They are easily explained by the new electron theory, for even solid crystals have ions which separate in water solution. However, the process of dissociation in concentrated solutions of strong electrolytes still presents an anomaly. Ghosh, an Indian scientist, in 1918, attempted to explain it but did not altogether succeed. Recently, P. Debye and Hückel advanced the theory of *complete* ionization even in strong electrolytes. By a thoroughly mathematical treatment, they showed that departures from the general law of dissociation were due to electrical forces between the ions. Others have suggested that the rôle of the solvent has not been sufficiently emphasized, and that, perhaps, ionization is preceded by a combination of solvent and solute.

¹³ George Johnstone Stoney, Secretary of the Royal Dublin Society, suggested, in 1891, the name electron as the "natural unit of electricity which would liberate one atom of hydrogen." He made no mention of its mass or inertia.

¹⁴ By R. A. S. Paget.

¹⁵ In 1917, the existence of element 91, the eka-tantalum of Mendeléeff's Table, was established by O. Hahn and L. Meitner in Germany. This radio-active element, parent of actinium, was first isolated as an oxide, ten years later, by Aristid V. Grosse at the Kaiser Wilhelm Institute in Berlin.

¹⁶ On Feb. 28, 1930, Dr. Fred Allison and Professor E. J. Murphy of the Alabama Polytechnic Institute at Auburn, Alabama, reported the existence of Element 87 in pollucite and lepidolite, two ores found in Maine. Using a new method of discovery, they detected minima of polarized light at points on a scale which

are characteristic of the predicted atomic mass and valence of this eka-caesium. It has, however, not as yet been separated either chemically or by positive-ray analysis.

¹⁷ From the "Ballad of Ryerson" by Edwin H. Lewis.

¹⁸ Langmuir has the unique distinction of receiving the Nichols Medal award of the American Chemical Society twice. In 1914, his paper on "Chemical Reactions at Low Temperatures" earned it for him.

¹⁹ A microscopic amount of this "synthetic gold" was brought to the United States on June 18, 1925 by H. Nagaoka of Tokyo, Japan.

²⁰ In 1925, Arthur H. Compton of the University of Chicago disclosed the fact that hard X-rays, which exhibited all the properties of light, showed a *lowering of frequency* after striking a metal plate. His photographs indicated that the X-rays bounced like balls rather than acted like waves. Two years later he received the Nobel Prize for this work and, soon after, from India came the announcement of the discovery of another somewhat similar effect. Chandrasekhara Venkata Raman, a Hindu scientist, detected that a beam of monochromatic light from a mercury vapor lamp was scattered by benzene, and new lines of *greater wave length* than the incident beam were revealed by the spectroscope. Both the Compton and Raman effects point to the probability that Einstein and de Broglie are right.

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A NOTE ABOUT THE AUTHOR

BERNARD JAFFE was born March 5, 1896, in New York City. He received the degree of B.S. *cum laude* from the College of the City of New York in June, 1916. He saw active service with the 108th Infantry, 27th Division in Belgium and France, attended the Gas School conducted by the Chemical Warfare Service at Langres, France, and in September, 1918, took part in the final drive on the Hindenburg line. After his army discharge he continued his studies at Columbia University and received the M.A. degree in chemistry in 1922.

While teaching chemistry at Jamaica High School, Jamaica, N. Y., he wrote *Chemical Calculations* which was published in March, 1926. This became a best-seller in its field. Early in that year, too, he began to collect material for a humanized story of the development of chemistry. Two years later the contest for *The Francis Bacon Award* was announced and he decided to compete. Altogether, four years were spent in the making of the book.

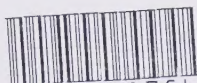
Crucibles is the winner of the \$7500 *Francis Bacon Award* sponsored by the Forum Magazine and Simon and Schuster. MR. JAFFE'S work was selected from several hundred manuscripts as best exemplifying that type of book which, in the phrase of James Harvey Robinson, shall "carry on the conscious adventure of humanizing knowledge". Among the members of the Jury of Award were the late Dr. Edwin E. Slosson, Dr. Will Durant, Dr. Henry Goddard Leach, and Count Hermann Keyserling. The gold medal emblematic of the *Francis Bacon*

Award was presented to MR. JAFFE by
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